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ECOLOGICAL REPORT SERIES

NORTHERN FLOOD AGREEMENT MANITOBA

Water Chemistry / Water Discharge Relationships Within the Churchill River Diversion and Lake Winnipeg Regulation Region, Manitoba, Canada

Number 88-5

Canada

Manitoba

WATER CHEMISTRY / WATER DISCHARGE RELATIONSHIPS WITHIN THE CHURCHILL RIVER DIVERSION AND LAKE WINNIPEG REGULATION REGION, MANITOBA, CANADA

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Water Standards and Studies Report

Acknowledgements

Funds for preparation of this report were provided by the Manitoba Department of Northern Affairs, Manitoba Hydro and Environment Canada. This study forms part of an Ecological Monitoring Program to address the Northern Flood Agreement and was coordinated by a 4-party Program Advisory Board.

Duncan, D.A. and D.A. Williamson. 1988. Water chemistry / water discharge relationships within the Churchill River diversion and Lake Winnipeg regulation region, Manitoba, Canada. Manitoba Department of Environment and Workplace Safety and Health. Water Standards and Studies Report # 87-8.

ABSTRACT

Statistically significant linear relationships were evident between a number of water chemistry parameters and discharge at various sites within the Churchill River diversion and Lake Winnipeg regulation region. Linear relationships that were similar and present both before and after development are most useful for providing corroborative evidence that water chemistry changes are coincident with development. These relationships are also beneficial in assisting focus of future field activities on events that may have the greatest impact upon water chemistry and in predicting potential water chemistry changes associated with future discharge alterations. Such relationships were observed for the parameters conductivity, alkalinity, calcium and chloride in the Burntwood River at Thompson, total phosphorus in the Churchill River upstream of Granville lake and conductivity and calcium in Little Playgreen Lake near Norway House.

Numerous relationships between water chemistry parameters and discharge have been significantly altered likely as a consequence of development. These relationships provide direct evidence that changes occurred within the system, but can only be used to indirectly corroborate previously identified water chemistry changes associated with development. Relationships that were statistically significant after development might be used cautiously to predict potential changes in water chemistry coincident with future alterations in discharge. Such relationships occurred for a number of parameters at most sites, including non-filterable residue, pH, total organic carbon, and total Kjeldhal nitrogen in the Burntwood River at Thompson, non-filterable residue, pH, alkalinity, magnesium, hardness, potassium, sodium and chloride in the Nelson River at Cross Lake, plus others.

Other parameters were not linearly related with discharge during either the pre-development or post-development period. Such parameters included sulphate and magnesium in the Burntwood River near Thompson, non-filterable residue, potassium, sodium, colour, chloride and sulphate in the Nelson River at Split Lake, plus others. This assessment indicates that relationships between water chemistry and discharge are complex and vary with location and time.

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1.0 INTRODUCTION

Manitoba Hydro, a provincial crown-corporation, has legislative authority to provide Manitoba's hydroelectric power requirements. Over two decades ago Manitoba Hydro recognized a need for greater hydroelectric generating capacity to meet a projected increase in demand for hydroelectric power. Lake Winnipeg, Churchill and Nelson Rivers (LWCNR) hydroelectric development was formulated to meet this projected increase. It involves Lake Winnipeg regulation (LWR), Churchill River diversion (CRD) into the Nelson River basin and installation of 14 generating stations.

Lake Winnipeg regulation utilized control works near the outlet of Lake Winnipeg at the Jenpeg generating station as well as various channels and dykes in the Outlet Lakes area to store water during summer for use during high demand periods in winter. Churchill River diversion involved construction of control structures at Missi Falls, the outflow of Southern Indian Lake (SIL) and at Notigi Lake to regulate Rat River flows and construction of a channel between South Bay, SIL and headwaters of the Rat River. The historical mean level of SIL was raised approximately three meters and about 75% of Churchill River flow (760 m^3/s) was diverted into the Rat River system to join with the Burntwood River at Threepoint Lake and enter the Nelson River at Split Lake. By mid-1976 both CRD and LWR were operational.

This study forms part of Manitoba's Department of Environment and Workplace Safety and Health and Environment Canada's commitment to the Northern Flood Agreement (Program Advisory Board 1987). Information in this report will address the following:

* Are water chemistry parameters linearly related to discharge?

* Do development-related changes in water quality correlate with development-related changes in discharge?

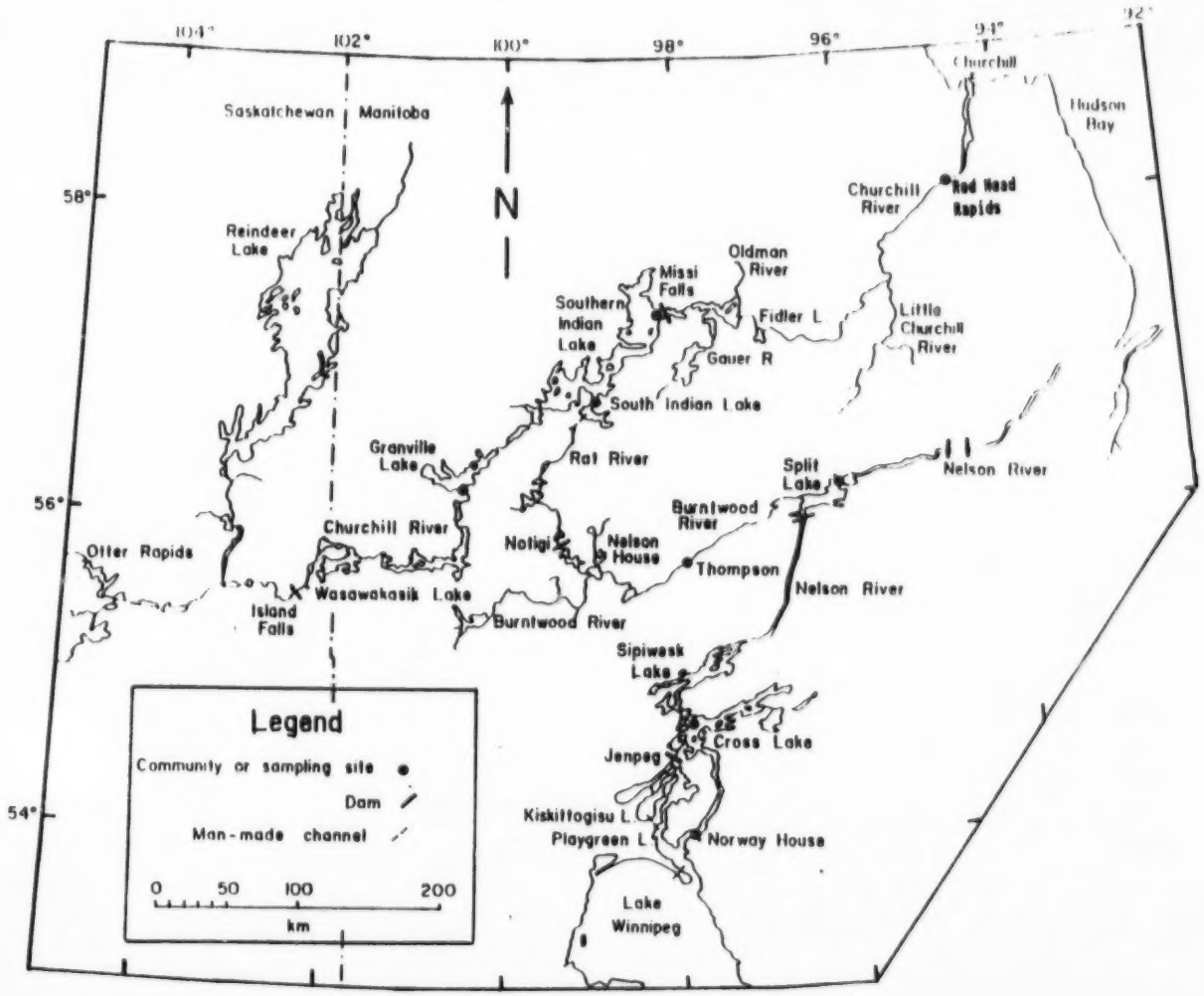
* Can linear regression analysis fascilitate development of a predictive model capable of describing water quality dynamics in northern lotic environments influenced by hydroelectric development?

This study was a follow-up to work done by Manitoba Environment and Workplace Safety and Health during 1985/86 in which statistically significant changes in some water chemisty parameters were recorded (Playle and Williamson 1986). Effects of discharge on lotic environments are controlled by several physical factors including: current velocity, quality of discharge, timing of discharge, fluctuation of flows, channel morphology, and substrate composition (Hynes 1971; Fraser 1972). Hypothesis testing was used to identify statistically significant linear relationships between individual water chemistry parameters and the natural logarithm (ln) of discharge records from various sites within the CRD and LWR region. This information analysis and identification of relationships will provide a comprehensive database for future studies and some insight into the complex nature and interrelatedness of water quality in the lotic environment of northern Manitoba.

2.0 STUDY AREA

The Churchill and Nelson Rivers, two of Canada's larger rivers, are located in northern Manitoba (Figure 1). The Churchill River drainage basin covers nearly 300,000 km^2 and extends through three provinces, while the Nelson River drainage basin covers slightly more than 1,000,000 km^2 and stretches from the Rocky Mountain foothills to the border of Lake Superior. Both rivers flow through extensive regions of Precambrian Shield overlain with glacio-lacustrine deposits and terminate in northern Manitoba where they flow into Hudson Bay. The Nelson River, unlike the Churchill, Rat or Burntwood Rivers, also drains a large prairie sedimentary area resulting in a greater concentration of dissolved solids than found in rivers draining only Shield

Figure 1. The Churchill River diversion and Lake Winnipeg regulation region, northern Manitoba (source: Playle and Williamson 1986).



regions. Lakes along these river systems are generally shallow, isothermal (i.e. no stratification), turbid, and typically riverine. Residence times of water in these lakes range from a few days to several years (Bodaly *et al.* 1984). Further details on the region's lakes, climate and geology are given in LWCNR Study Board (1975), Bodaly *et al.* (1984) and Newbury *et al.* (1984).

3.0 METHODS

3.1 Data Collection and Analyses

Manitoba Environment and Workplace Safety and Health has collected water quality data from the CRD and LWR region since 1972. Water samples were collected at a depth of 0.5-1.0 m during both ice-free and ice-covered periods. Samples were analyzed at W.M. Ward Technical Services Laboratory in accordance with methods described by Sorba *et al.* (1980). Water chemistry data from this database were supplemented with compatible data supplied by Canada Departments of Environment and Fisheries & Oceans. Appropriate water discharge data for various sites were obtained from Environment Canada (Water Survey of Canada), Manitoba Department of Natural Resources (Water Resources Branch) and Manitoba Hydro. Discharge records included annual means, monthly means, daily discharge for dates water chemistry samples were collected, minimum and maximum flows and date of occurence.

3.2 Data Compilation and Selection

Selected water quality parameters and daily discharge data were compiled in a computerized database with a separate data set for each of eight sites. Parameters selected for regression analyses and their selection criteria were the same as described by Playle and Williamson (1986). However rather than

using mid-1976 as a reference point for dividing data into pre- and post-development subsets, data collected prior to 1976 represented pre-development and data collected after 1976 (i.e. since 1977) represented post-development. Data collected during 1976 were omitted from regression analyses due to possible anomalies resulting from start-up activities of CRD and LWR projects.

The sites selected for regression analyses included 7 of the 10 sites in Playle and Williamson (1986) as well as Red Head Rapids on the lower Churchill River. Red Head Rapids was selected as a site for analysis largely due to its location being relatively distant from major lakes, thereby minimizing the influence lakes exert on water quality/discharge relationships. Sipiwesk Lake, Nelson House and the Churchill water intake sites were omitted from regression analyses due to difficuties in obtaining appropriate discharge and/or water chemistry data for those locations. Water quality monitoring stations located on lakes where discharge data was not available, necessitated the use of discharge records from the nearest applicable river station for regression analyses. Split Lake discharge data were calculated by summing records from Kelsey generating station and Thompson to account for inflows from both the Nelson and Burntwood Rivers, respectively.

3.3 Statistical Analyses

Individual water chemistry parameters were regressed against the ln of daily discharge data for each site and correlation coefficients calculated. A linear model was selected as there was no a priori reason for selecting a higher order polynomial and in most instances a 2^{nd} or 3^{rd} order polynomial did not significantly improve the model's fit. The line of best fit, calculated using the method of least squares, had the linear equation: $y = a + bx$

where: y = predicted value for parameter of interest
a = estimate of y-intercept, α
b = estimate of slope, β
x = ln(discharge)

A test of the null hypothesis, H_0: $\beta=0$ (i.e. slope = 0) with the alternative hypothesis, H_a: $\beta\neq0$, was conducted to determine if there was a significant linear relationship between a particular parameter and ln discharge. The test statistic was:

$$t = b / s_b$$

where: t = t-statistic
b = estimate of slope, β
s_b = standard error of b

with n-2 degrees of freedom and a 5% level of significance. If the t-statistic was outside the critical region of t, derived from standard t-tables, the null hypothesis was rejected and it was concluded that the parameter was linearly related to ln discharge (i.e. slope $\neq$ 0).

The correlation coefficient (r) measures the degree of linear association between variables, in this report, between water chemistry parameters and ln discharge. It may have any value between -1 and +1 inclusive. The closer r is to -1 or +1 the higher the degree of linear association. When all points lie exactly on a straight line, r equals -1 or +1 and if there is no linear correlation (i.e. b = 0) r equals zero. An r value of zero does not preclude the existence of a significant curvilinear relationship between variables. A correlation between two variables does not necessarily mean that a change in one causes a change in the other. The correlation coefficient, r, will always have the same sign as b (slope). A positive correlation (slope is upward to the right) means that as ln discharge increases so does the value of the water chemistry parameter. A negative, or inverse, correlation (slope is downward to the right) means as ln discharge increases the value of the water chemistry parameter decreases.

All statistical analyses and data manipulations were done on an IBM PC XT using NWA STATPAK, Version 4.1, a multi-function statistics library (Northwest Analytical Inc. 1986).

4.0 RESULTS AND DISCUSSION

The following sections contain specific information on significant linear relationships between water chemistry and discharge data as well as graphs of discharge vs time for each location. Equations of regression lines for each parameter that was linearly related to ln discharge are listed in Table 1. Graphs of regression lines for water chemistry parameters vs ln discharge and summary tables of discharge information are provided in Appendices A and B respectively.

It is unrealistic to expect water chemistry parameters to be solely dependent upon a single variable, such as discharge. However, this report shows that changes in discharge frequently account for a significant amount of some parameters' variation. In instances where regression equations were similar between pre- and post-1976 data, the equations can provide direct corroborative evidence that changes in discharge were responsible for the altered water chemistry values reported by Playle and Williamson (1986). When these linear relationships change substantially or are absent before or after development then they can provide only indirect evidence that changes observed in water quality resulted from alterations in discharge. These changes in relationships between water chemistry parameters and discharge do provide direct evidence of significant alteration within the aquatic environment, since LWR and CRD.

Table 2 lists r values of regression lines for statistically significant linear relationships only. A significant linear relationship does not "prove" a cause-and-effect relationship (i.e. a change in discharge may not be the cause of a change in water quality). Two unrelated variables may appear correlated with each other, if both are highly correlated with a third variable. Hence, ecological significance of correlation coefficients must be interpreted with caution.

Table 1. Linear equations for regression lines of parameter values vs ln discharge. Only equations with statistically significant relationships are presented (----- = no significant relationship; isd = insufficient data).

LOCATION	PARAMETER	PERIOD	
		PRE-1976	POST-1976
Churchill River:			
Granville Lake	Mg	-----	y= 39.5 - 5.55 * ln(x)
	TOC	-----	y= 30.8 - 3.18 * ln(x)
	Turb.	y= -19.9 + 3.46 * ln(x)	-----
	TKN	-----	y= 1.97 - .239 * ln(x)
	Tot. P	y= .133 - .0169 * ln(x)	y= .0728 -.0077 * ln(x)
South Indian Lake	Colour	isd	y= -21.3 + 5.24 * ln(x)
	SO_4	isd	y= 55.1 - 7.74 * ln(x)
Missi Falls	TIC	isd	y= 13.1 - .379 * ln(x)
	Colour	isd	y= 51.5 - 6.27 * ln(x)
Red Head Rapids	Cond.	-----	y= 263 - 20.9 * ln(x)
	NFR	-----	y= -18.6 + 4.38 * ln(x)
	Alkal.	-----	y= 140 - 12.6 * ln(x)
	Ca	-----	y= 36.3 - 2.72 * ln(x)
	Mg	-----	y= 9.23 - .746 * ln(x)
	Hard.	-----	y= 126 - 9.11 * ln(x)
	K	y= 7.85 - .917 * ln(x)	-----
	TOC	-----	y= 1.99 + 1.22 * ln(x)
	Colour	-----	y= -53.4 + 16.5 * ln(x)
	Turb.	-----	y= -16.7 + 3.81 * ln(x)
Burntwood River:			
Thompson	Cond.	y= 194 - 12.3 * ln(x)	y= 194 - 12.2 * ln(x)
	NFR	-----	y= -94.0 + 17.0 * ln(x)
	pH	-----	y= 5.68 + .326 * ln(x)
	Alkal.	y= 90.8 - 6.02 * ln(x)	y= 129 - 11.3 * ln(x)
	Ca	y= 28.4 - 1.72 * ln(x)	y= 48.1 - 4.78 * ln(x)
	Hard.	y= 96.1 - 6.25 * ln(x)	-----
	K	y= 1.17 - .041 * ln(x)	-----
	Na	y= 4.23 - .390 * ln(x)	-----
	TOC	-----	y= 30.0 - 2.80 * ln(x)
	TIC	y= 25.6 - 2.83 * ln(x)	y= 32.9 - 3.12 * ln(x)
	Colour	y= 15.5 + 7.51 * ln(x)	y= -104 + 21.5 * ln(x)
	Turb.	y= -3.91 + 4.58 * ln(x)	y= -53.4 + 11.0 * ln(x)
	TKN	-----	y= 2.98 - .387 * ln(x)
	Tot. P	y= .0090 + .0052 * ln(x)	-----
	Cl	y= 2.93 - .368 * ln(x)	y= 3.37 - .362 * ln(x)

Table 1. - continued:

LOCATION	PARAMETER	PERIOD	
		PRE-1976	POST-1976
Nelson River:			
Split Lake	Cond.	y= 974 - 86.2 * ln(x)	y= -429 + 84.8 * ln(x)
	pH	-----	y= 10.5 - .312 * ln(x)
	Alkal.	y= 331 - 29.2 * ln(x)	-----
	Ca	y= 138 - 13.6 * ln(x)	-----
	Mg	y= 110 - 12.6 * ln(x)	-----
	Hard.	y= 365 - 31.3 * ln(x)	-----
	TOC	-----	y= -12.1 + 3.16 * ln(x)
	TIC	-----	y= -9.46 + 3.67 * ln(x)
	Turb.	y= -93.3 + 13.7 * ln(x)	-----
	Tot. P	y= -.236 + .0337 * ln(x)	-----
Norway House	Cond.	y= 547 - 41.1 * ln(x)	y= 566 - 48.3 * ln(x)
	pH	-----	y= 7.27 + .133 * ln(x)
	Alkal.	-----	y= 166 - 12.4 * ln(x)
	Ca	y= 50.4 - 3.34 * ln(x)	y= 57.3 - 5.17 * ln(x)
	Mg	-----	y= 19.4 - 1.60 * ln(x)
	Hard.	y= 190 - 12.5 * ln(x)	-----
	TIC	-----	y= 42.7 - 3.68 * ln(x)
	Turb.	-----	y= -2.73 + 1.81 * ln(x)
	TKN	y= 3.70 - .493 * ln(x)	-----
Cross lake	NFR	-----	y= 62.5 - 7.41 * ln(x)
	pH	-----	y= 10.2 - .302 * ln(x)
	Alkal.	-----	y= -68.0 + 23.5 * ln(x)
	Mg	-----	y= -4.04 + 2.18 * ln(x)
	Hard.	-----	y= -64.3 + 25.8 * ln(x)
	K	-----	y= -11.5 + 2.06 * ln(x)
	Na	-----	y= -123 + 20.1 * ln(x)
	Cl	-----	y= -120 + 20.1 * ln(x)
	SO_4	y= 76.1 - 6.05 * ln(x)	-----

Table 2. Correlation coefficients (r) and sample size (n) from regression lines of parameter values vs ln discharge. Only r and n values from plots with statistically significant linear relationships are presented (* = no significant relationship).

LOCATION	PERIOD	COND.	MFR	pH	ALKAL.	Ca	Mg	HARD.	K	Na	TOC	TIC	COLOR	TURB	TKN	TOT. P	Cl	SO_4
CHURCHILL RIVER:																		
GRANVILLE LAKE	PRE-76	*	*	*	*	*	*	*	*	*	*	*	*	.421 (28)	*	-.431 (21)	*	*
	POST-76	*	*	*	*	*	-.572 (16)	*	*	*	-.501 (18)	*	*	*	-.386 (37)	-.315 (38)	*	*
SOUTH INDIAN LAKE	POST-76	*	*	*	*	*	*	*	*	*	*	*	.891 (05)	*	*	*	*	-.951 (05)
MISSI FALLS	POST-76	*	*	*	*	*	*	*	*	*	*	-.493 (26)	-.568 (13)	*	*	*	*	*
RED HEAD RAPIDS	PRE-76	*	*	*	*	*	*	*	-.611 (13)	*	*	*	*	*	*	*	*	*
	POST-76	-.573 (30)	.542 (28)	*	-.660 (29)	-.545 (30)	-.544 (28)	-.503 (21)	*	*	.682 (21)	*	.658 (30)	.545 (30)	*	*	*	*
BURNTWOOD RIVER:																		
THOMPSON	PRE-76	-.705 (89)	*	*	-.672 (90)	-.549 (85)	*	-.743 (85)	-.220 (90)	-.707 (89)	*	-.767 (42)	.498 (89)	.433 (88)	*	.319 (42)	-.571 (89)	*
	POST-76	-.286 (53)	.535 (46)	.398 (54)	-.576 (37)	-.499 (36)	*	*	*	*	-.441 (33)	-.475 (33)	.535 (15)	.441 (30)	-.293 (47)	*	-.527 (15)	*
NELSON RIVER:																		
SPLIT LAKE	PRE-76	-.533 (22)	*	*	-.597 (22)	-.661 (22)	-.797 (06)	-.512 (22)	*	*	*	*	*	.437 (22)	*	.604 (19)	*	*
	POST-76	.510 (41)	*	-.494 (41)	*	*	*	*	*	*	.345 (41)	.332 (41)	*	*	*	*	*	*
NORWAY HOUSE	PRE-76	-.490 (27)	*	*	*	-.385 (27)	*	-.391 (27)	*	*	*	*	*	*	-.646 (17)	*	*	*
	POST-76	-.457 (44)	*	.369 (44)	-.423 (27)	-.584 (25)	-.451 (25)	*	*	*	*	-.468 (44)	*	.529 (19)	*	*	*	*
CROSS LAKE	PRE-76	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	-.391 (34)
	POST-76	*	-.520 (47)	-.473 (47)	.524 (30)	*	.378 (29)	.665 (09)	.738 (08)	.877 (08)	*	*	*	*	*	*	.856 (08)	*

4.1 Churchill River

4.1.1 Granville Lake

Five water quality parameters were linearly correlated to ln discharge data from the Churchill River upstream of Granville Lake. The five parameters were total phosphorous (Tot. P), turbidity, magnesium (Mg), total organic carbon (TOC) and total Kjeldahl nitrogen (TKN). Total P exhibited a negative correlation in both pre-1976 and post-1976 testing, but was not a particularly strong relationship post-development; turbidity exhibited a positive linear relationship in pre-1976 data only; Mg, TOC and TKN exhibited a negative linear relationship in post-1976 data only. The data range for Tot. P values was very small (0.01 - 0.03 mg(P)/L for post-1976 data) and the linear relationship may not be valid outside this rather narrow range. The linear relationship between Mg and ln discharge only covered a rather limited range of discharge (520 - 841 m^3/s) and extrapolation beyond these limits may not be valid.

Playle and Williamson (1986) reported statistically significant changes in the mean levels of six water chemistry parameters from this site. Only two of those parameters, TKN and Tot. P, were linearly correlated to ln discharge. The increase in Tot. P values detected by Playle and Williamson (1986) coincides with the inverse relationship between Tot P and ln discharge, considering the approximate 14% reduction in discharge, post-1976.

Although the site upstream of Granville Lake was not affected by CRD or LWR, hydroelectric projects further upstream in Saskatchewan, would have effects on both quantity and quality of water at this location. Granville Lake discharge can be viewed as fairly typical of riverine discharge patterns with substantial seasonal fluctuations (Figure 2). There is also a long-term cycle to discharge patterns which is clearly visible when discharge is plotted over a longer time scale (Figure 3). Although discharge in recent years has been

Figure 2. Discharge pattern for Granville Lake. Lines connect monthly mean discharge data (m^3/s) from Granville Falls during 1968 - 1984. There is some missing data during 1980 and 1981. * = Annual mean discharge (m^3/s).

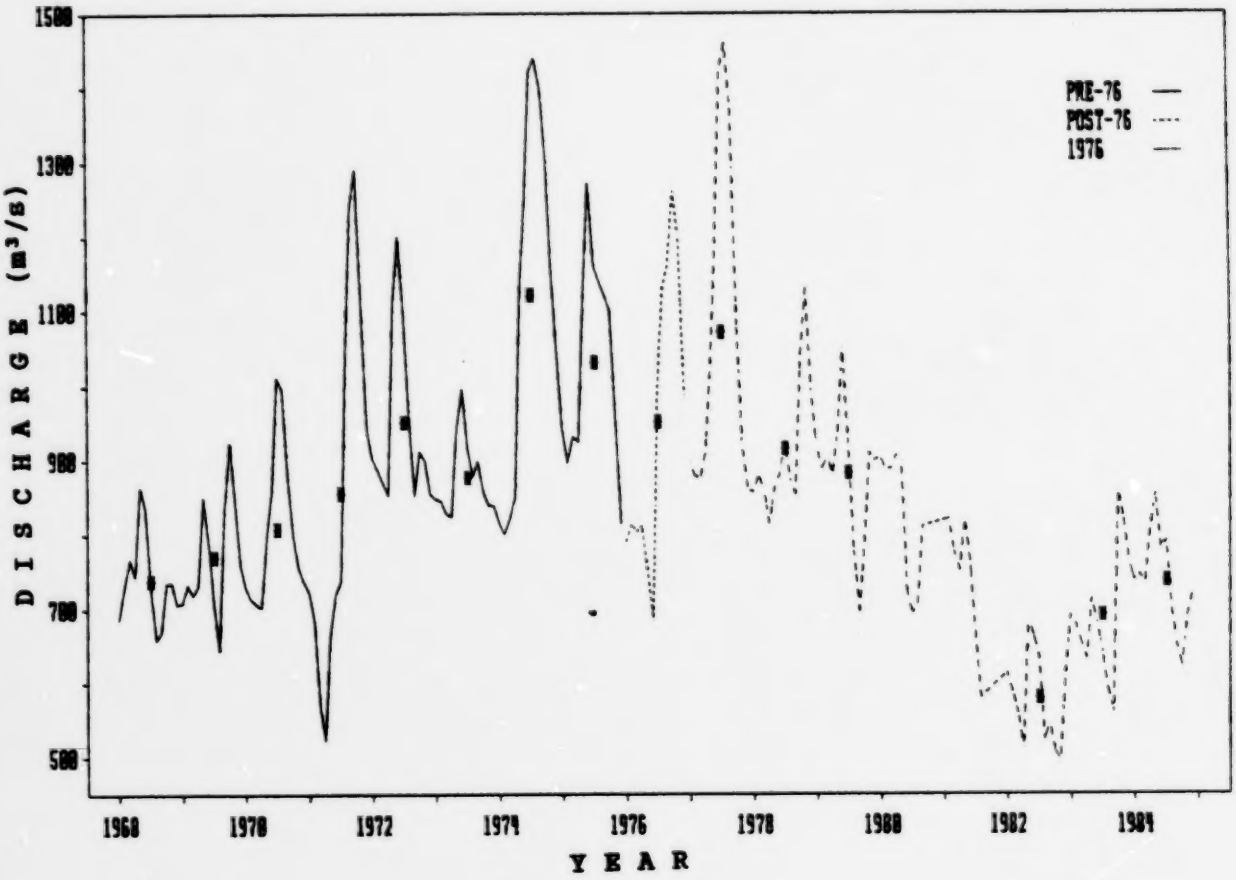
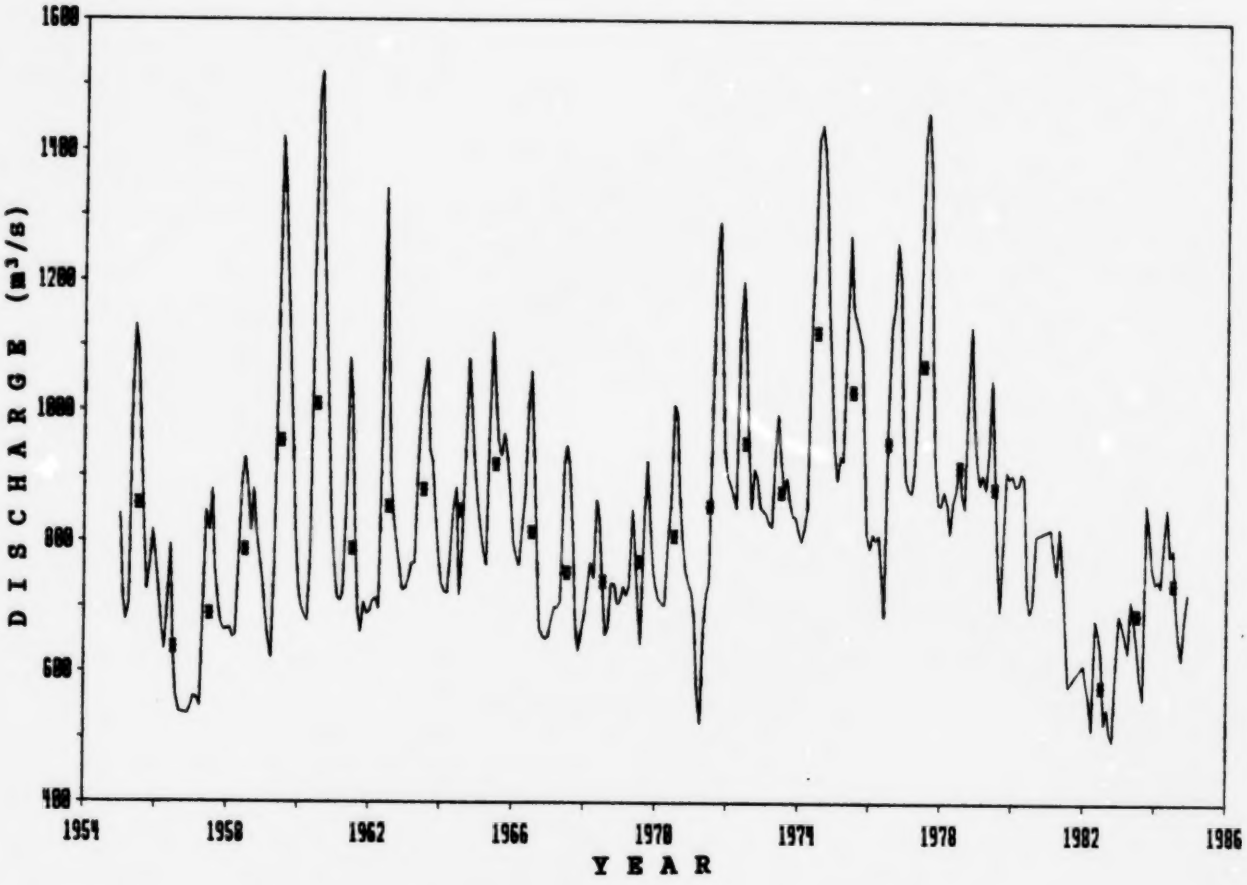


Figure 3. Long-term discharge pattern for Granville Lake. Lines connect monthly mean discharge data (m^3/s) from Granville Falls during 1955 - 1984. There is some missing data during 1980 and 1981. * = Annual mean discharge (m^3/s).



relatively low, parameters such as Mg, TOC, TKN and Tot. P might be expected to decrease, with a return to higher discharge, if present water chemistry / water discharge relationships are maintained. Such cycles and their consequences can only be detected and accurately interpreted through long-term monitoring programs.

4.1.2 Southern Indian Lake - South Indian Lake & Missi Falls

Few water chemistry parameters from SIL were linearly correlated to ln discharge; only post-1976 data could be analyzed due to the lack of pre-development discharge records. Color, sulphate (SO_4), and total inorganic carbon (TIC) were the only parameters linearly correlated to ln discharge. There were no significant differences in the mean values of these parameters between pre-1976 and post-1976 data sets (Playle and Williamson 1986), despite extreme changes in discharge patterns and flushing rates. Very high correlation coefficients (r=.89 & -.95) were obtained for the linear regressions at South Indian Lake between two water chemistry parameters (color and SO_4) and ln discharge but they were derived from a small sample size (n=5), and covered a narrow range of flows (308-910 m^3/s) and parameter values. Significant linear relationships between color and ln discharge were present at all sites along the Churchill and Burntwood Rivers, except at the Granville Lake location. This linear relationship between color and ln discharge was not observed at any site along the Nelson River.

It is clear from the discharge graph for South Bay, SIL, that flows are carefully regulated, seasonal fluctuations are relatively small and annual mean discharge values are relatively constant (Figure 4). The graph of discharge data for Missi Falls clearly illustrates the greatly reduced outflow from SIL into the lower Churchill River and the relatively small seasonal fluctuations (Figure 5).

Figure 4. Discharge pattern for South Indian Lake. Lines connect monthly mean discharge data (m^3/s) from South Bay during 1976 - 1984. There is some missing data during 1976. * = Annual mean discharge (m^3/s).

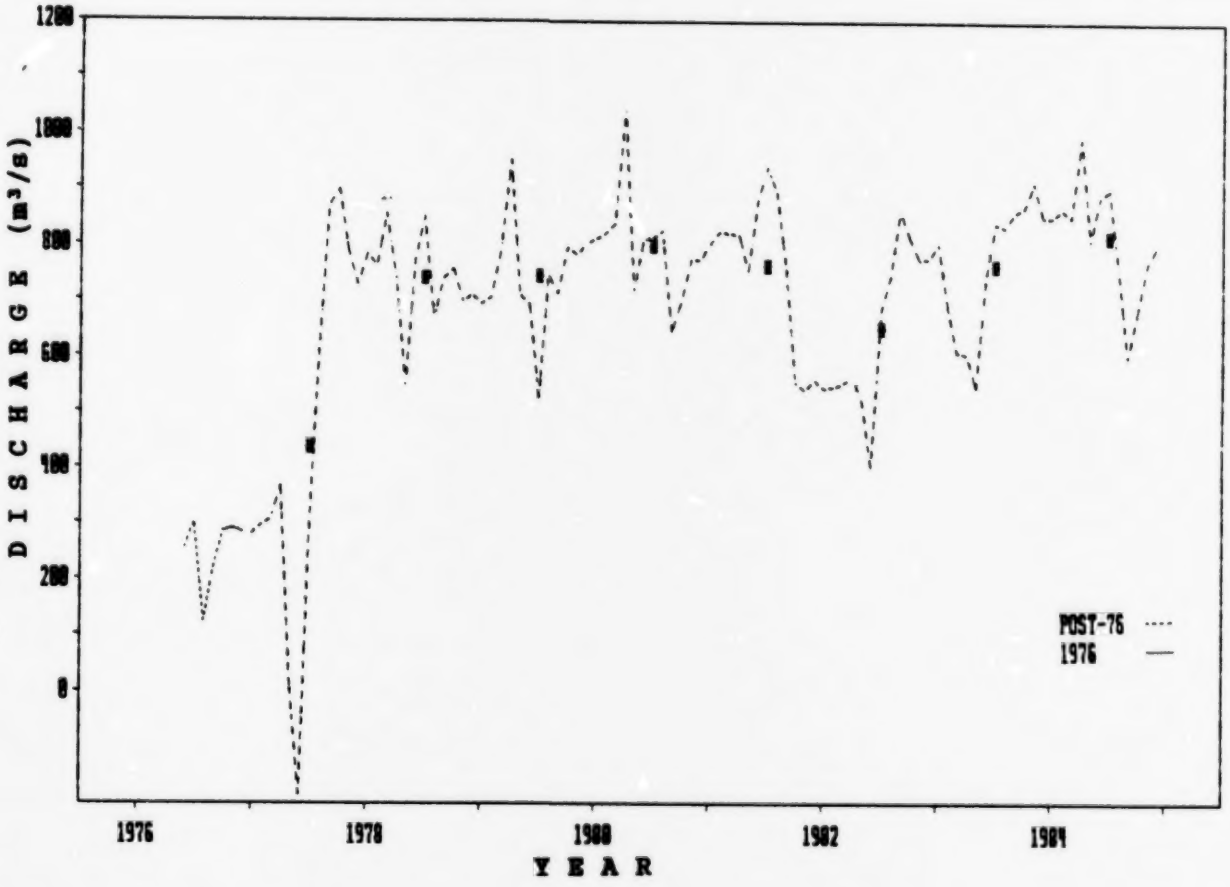
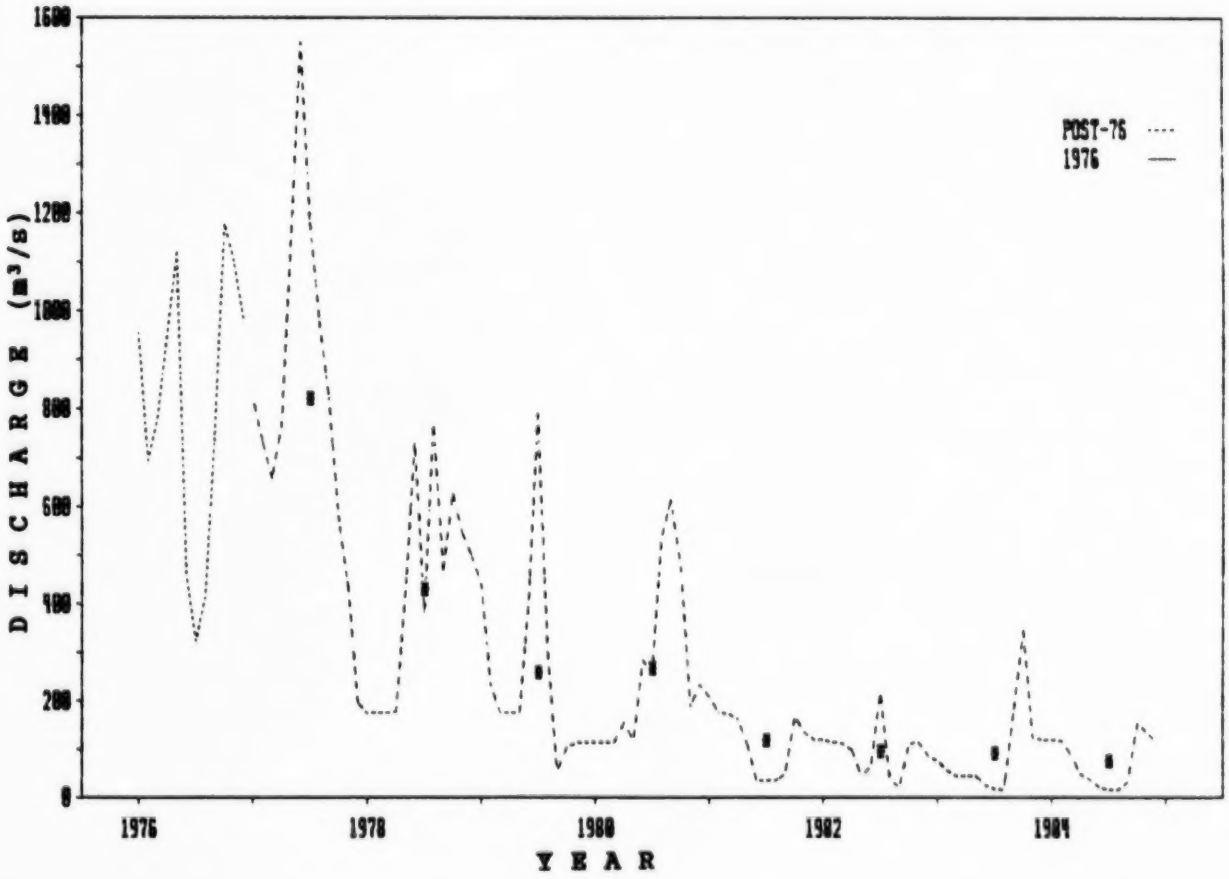


Figure 5. Discharge pattern for Missi Falls. Lines connect monthly mean discharge data (m^3/s) during 1976 - 1984. There is some missing data during 1976. * = Annual mean discharge (m^3/s).



4.1.3 Lower Churchill River - Red Head Rapids

Ten water chemistry parameters were linearly correlated with ln discharge data from Red Head Rapids. These linear relationships were quite strong with all r values greater than 0.5 (ignoring the sign). Conductivity, alkalinity, calcium (Ca), Mg and hardness were inversely correlated to ln discharge while non-filterable residue (NFR), TOC, color and turbidity were positively correlated with ln discharge. Only one parameter (potassium) was correlated with ln discharge prior to 1976 while there were 9 linear relationships after 1976. It is apparent that water quality at Red Head Rapids was quite dependent on ln discharge after 1976.

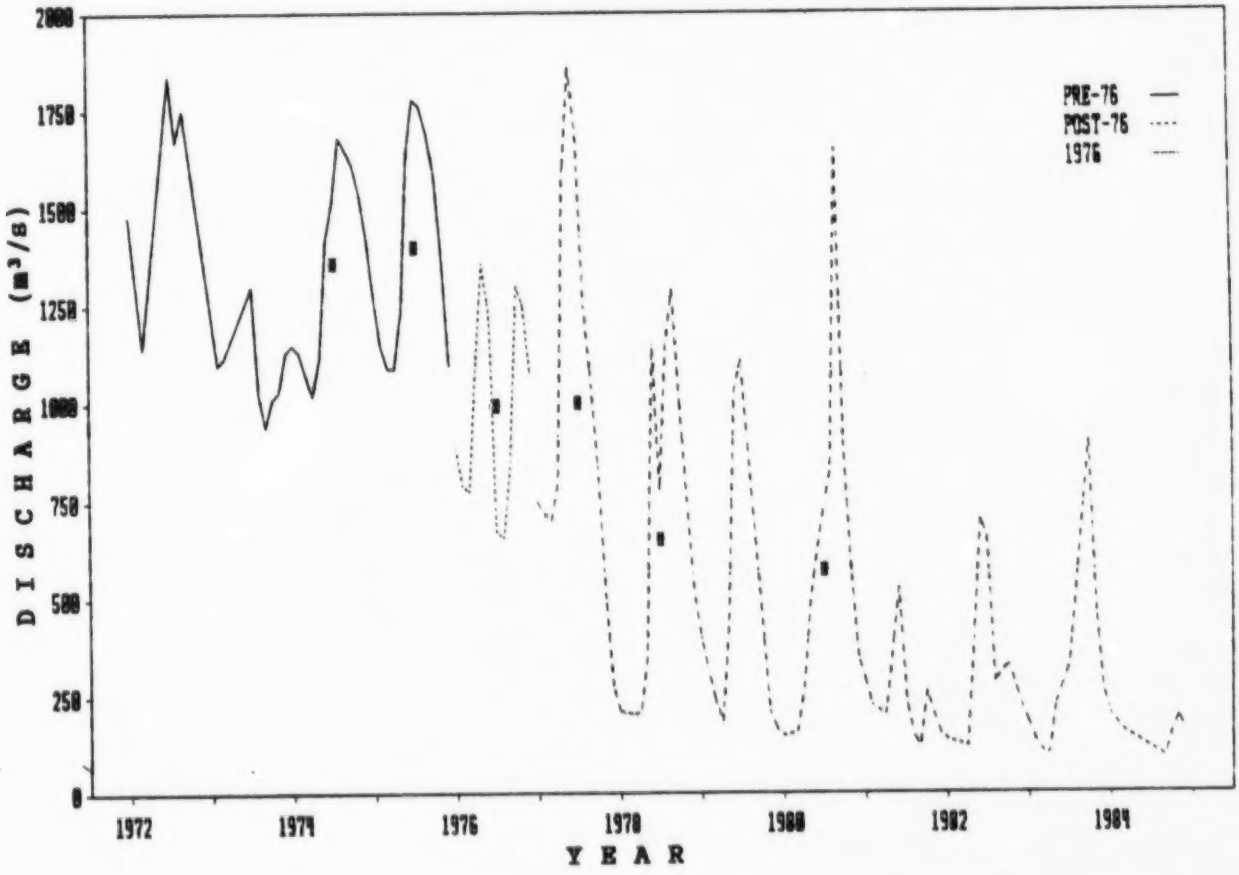
Discharge was greatly reduced post-development and the relative seasonal fluctuation in flows increased considerably (Figure 6). Spring freshets and heavy precipitation influence a river's water chemistry by large additions of soft water. These additions will have a greater effect on rivers with low discharge than on rivers with high discharge. Soft water is less stable chemically than hard water (Hynes 1971) and large additions of soft water will create shifts, at least temporarily, in chemical equillibria within the river. Local tributaries and runoff became more important in determining water quality due to their increased proportional contribution to discharge, from 8% prior to CRD to 37% post CRD (LWCNR Study Board 1975). This reduced flow, increased variation and increased local influences may all function to create significant linear relationships between various water quality parameters and ln discharge.

4.2 Burntwood River

4.2.1 Thompson

Numerous water quality parameters were linearly correlated with ln discharge data from Thompson. Significant linear relationships existed between

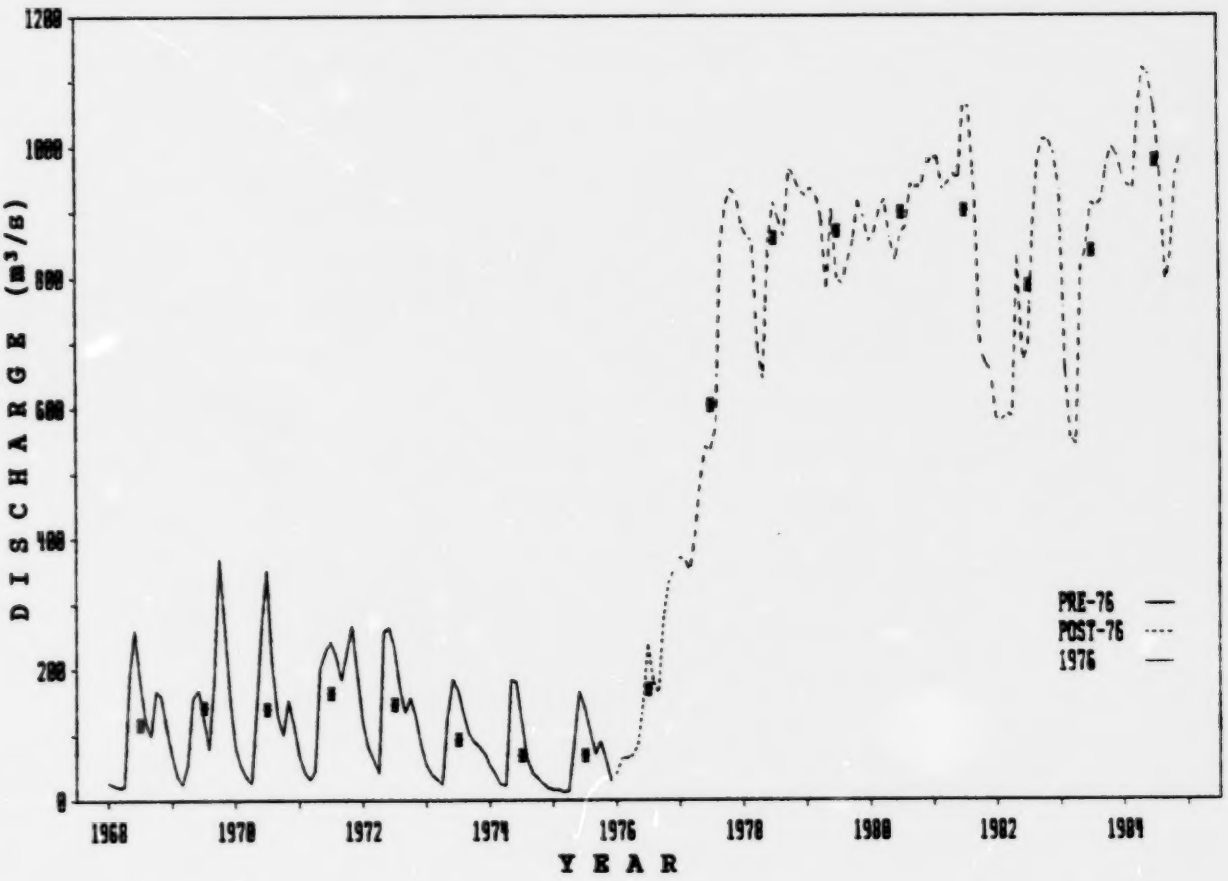
Figure 6. Discharge pattern for Red Head Rapids. Lines connect monthly mean discharge data (m^3/s) during 1972 - 1984. There is some missing data during 1972, '73, '79 and 1981-'84. * = Annual mean discharge (m^3/s).



15 water chemistry parameters and ln discharge, more than at any other location. Seven of these linear relationships were present both before and after 1976. Regression lines for pre-1976 conductivity and chloride (Cl) vs ln discharge, and to a lesser extent lines for alkalinity and Ca, would have served as good predictors of post-1976 parameter values. Post-development regression lines for these parameters would be very close to pre-1976 regression lines extrapolated to include the increased discharge levels. Conductivity, alkalinity, Ca, TIC and Cl were negatively correlated with ln discharge, both before and after 1976, while color and turbidity were positively correlated with ln discharge during both periods. Hardness, potassium (K), sodium (Na) and Tot. P exhibited linear relationships prior to 1976 but not after; similarly NFR, pH, TOC and TKN exhibited linear relationships post-1976 but not before. No reversals of trends from positive to negative correlations or vice-versa occurred. The correlation coefficients for K and TKN are both relatively weak as was the coefficient for conductivity from the post-1976 data. Only three parameters (Mg, SO_4 and nitrate+nitrite) were not linearly related to ln discharge during either period, thus emphasizing the potential importance of discharge to water quality in riverine systems.

Playle and Williamson (1986) recorded statistically significant changes in the mean levels of seven water chemistry parameters from this site. All these parameters, except Mg, were linearly correlated to ln discharge. Decreased conductivity, alkalinity, Ca and TIC values detected by Playle and Williamson (1986) coincided with inverse correlations between these parameters and ln discharge, considering the approximate 10-fold increase in discharge, post-1976. Similarly increased Tot. P and NFR values coincided with positive correlations between these two parameters and ln discharge. It is presently uncertain why color and turbidity values did not significantly increase considering their positive correlation with ln discharge both pre- and post-1976.

Figure 7. Discharge pattern for Thompson. Lines connect monthly mean discharge data (m^3/s) during 1968 - 1984. * = Annual mean discharge (m^3/s).



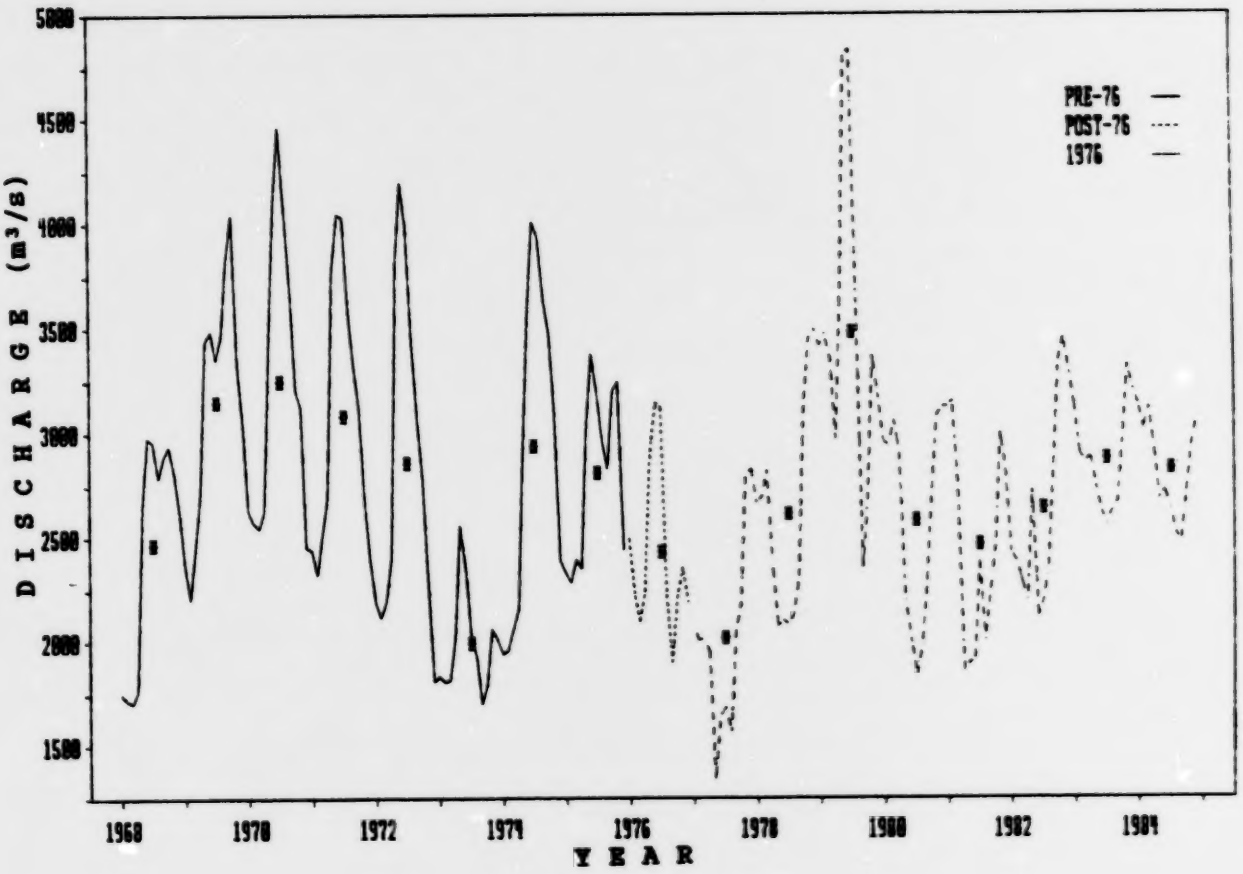
Differences between pre-1976 and post-1976 relationships were likely a result of the nearly 10-fold increase in Burntwood River discharge (Figure 7). The subsequent diminished importance of local tributaries and runoff could have accounted for the post-1976 lack of linear relationships in parameters such as hardness, K and Na. Also dilution effects of precipitation and runoff could have been reduced by the higher discharge rates. Regular seasonal fluctuations in discharge observed prior to 1976 were somewhat erratic post-1976. The large rapid increase in discharge, concomitant increase in energy passing down the system and increased erosion potential could account for the post-development appearence of linear relationships in parameters such as NFR and TOC.

4.3 Nelson River

4.3.1 Split Lake

Ten water quality parameters were linearly correlated with ln discharge at Split Lake. Mean values for conductivity, alkalinity, Ca, Mg and hardness after 1976 were significantly less than before 1976 (Playle and Williamson 1986). All these parameters were inversely correlated to ln discharge before 1976 while conductivity was positively correlated after 1976. Mean values for turbidity and TOC after 1976 were significantly greater than before 1976 (Playle and Williamson 1986). Turbidity and TOC were positively correlated with ln discharge pre- and post-1976 respectively. With the exception of post-1976 conductivity, all these linear relationships appeared to indicate an increased discharge, if discharge was solely responsible for changes in mean water chemistry values. Burntwood River discharge was greatly increased, however annual mean discharge for Split Lake did not reflect this increase (Figure 8) due to decreased discharge along the Nelson River. Nelson River mean discharge, at Kelsey generating station and Bladder Rapids, for eight years immediately

Figure 8. Discharge pattern for Split Lake. Lines connect the sums of monthly mean discharge data (m^3/s) from Kelsey G.S. and Thompson during 1968 - 1984. * = Annual mean discharge (m^3/s).



following 1976 was about 30% less than for eight years immediately prior to 1976. Despite increased Burntwood River discharge into Split Lake after CRD, mean Nelson River discharge downstream of Split Lake at Kettle Rapids was still 20% less than it was prior to LWR and CRD according to monthly flow simulations (unpublished data, Manitoba Hydro). These counteracting discharge rates add to the complexity of water chemistry/discharge relationships present in lakes and make predictions of future results less certain.

Water chemistry / water discharge relationships at Split Lake were substantially different before 1976 than after 1976. The natural discharge pattern of peak flows occurring in late spring and minimum discharge occurring in winter were reversed post-development in order to maximize generating potential at times of high demand. Nearly twice as many linear correlations existed prior to 1976 as there were post-1976. This is in contrast to Granville Lake, Red Head Rapids, Norway House and Cross Lake where water chemistry parameters were much more likely to be correlated with ln discharge after 1976 than before. Conductivity was the only parameter to have a linear relationship with ln discharge both before and after 1976; however the normal inverse relationship before 1976 reversed to a positive one after 1976. Split Lake was the only site where a positive correlation between conductivity and ln discharge was recorded. Similarly the positive correlation between TIC and ln discharge was contrary to that at other sites. Reasons for these differences are unclear but likely involve increased input of soft Burntwood River water, presence of mixing zones and/or the shift in seasonal discharge patterns.

4.3.2 Norway House

Nine water quality parameters were linearly correlated with ln discharge at Norway House. Nearly twice as many parameters were correlated with ln discharge after 1976 as before 1976. There was no reversal in seasonal discharge

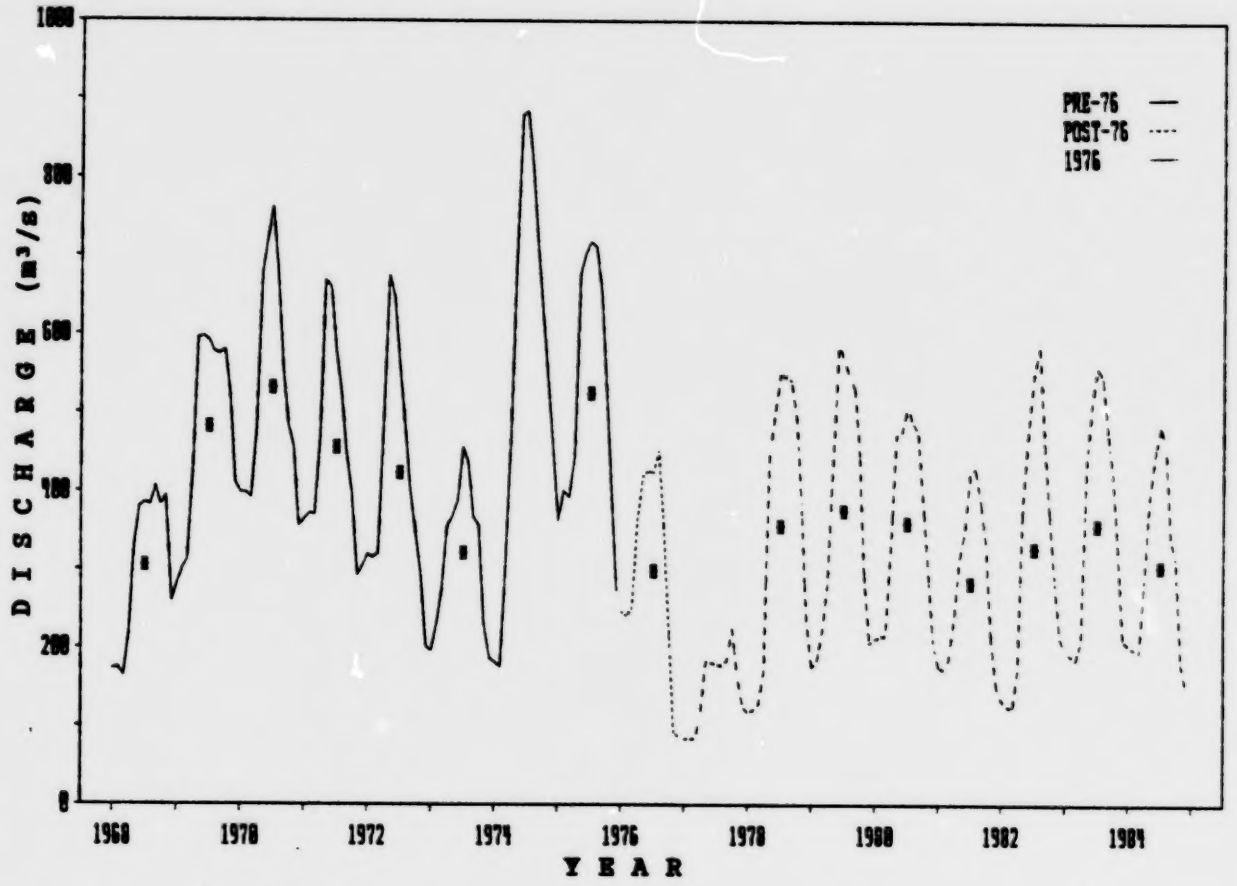
patterns at Norway House after LWR, however there was almost 25% reduction in discharge (Figure 9). Playle and Williamson (1986) recorded significant changes in pre- and post-1976 mean values of Tot. P, TOC, SO_4, TIC, TKN, and turbidity. Only the latter three were linearly related to ln discharge and only the inverse relationship for TIC concurred with the reported increased mean parameter value, considering the reduced discharge. Conductivity, Ca, hardness and TKN were all inversely proportional to ln discharge before 1976. Positive relationships did not exist prior to 1976. After 1976, only conductivity and Ca were relatively unchanged, hardness and TKN were no longer linearly related to ln discharge. Regression lines for pre-1976 conductivity and Ca vs ln discharge would have served as adequate predictors of post-1976 parameter values. Alkalinity, Mg and TIC which were not dependent on flow prior to 1976 were all inversely correlated with ln discharge after 1976; similarly pH and turbidity were positively correlated to ln discharge post-1976.

4.3.3 Cross Lake

There were significant linear relationships between 9 water quality parameters and ln discharge at Cross Lake. Playle and Williamson (1986) recorded significant changes between pre- and post-1976 mean values for seven water chemistry parameters at this site. Only two of these parameters (K and Cl) have significant linear relationships with ln discharge; both had a positive correlation with ln discharge post-1976 and no significant linear relationship before 1976. These positive correlations for K and Cl appear contrary to the findings reported by Playle and Williamson (1986), considering the nearly 30% reduction in discharge from pre-1976 to post-1976. The fact that there were no significant linear relationships for K and Cl vs ln discharge prior to 1976 may partially account for these apparent contradictions.

Water chemistry / water discharge relationships at Cross Lake were

Figure 9. Discharge pattern for Norway House. Lines connect the monthly mean discharge data (m^3/s) from Sea River Falls during 1968 - 1984. There is some missing data during 1974 and 1977. * = Annual mean discharge (m^3/s).

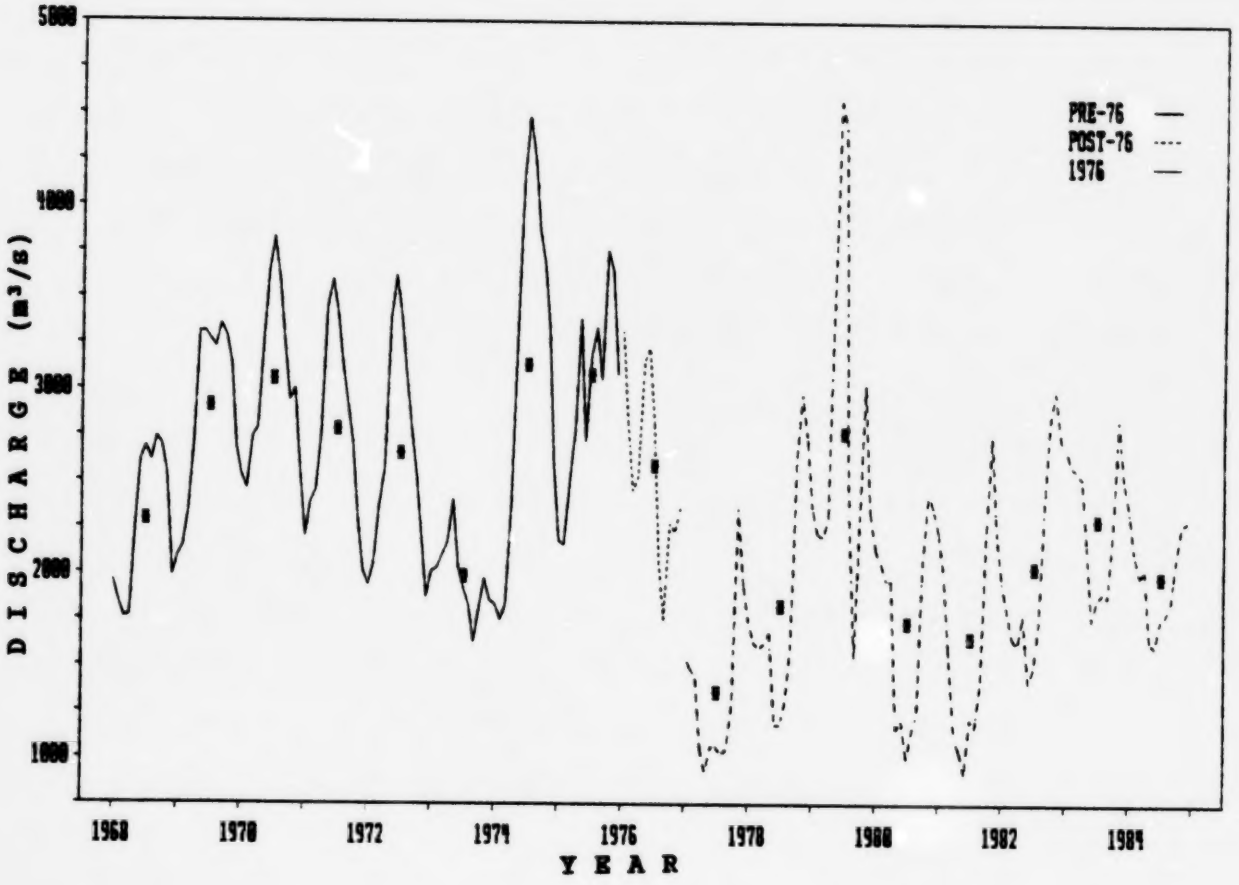


considerably altered since LWR. Only SO_4 was linearly dependent on ln discharge prior to 1976, whereas NFR, pH, alkalinity, Mg, hardness, K, Na and Cl were all linearly correlated to ln discharge after 1976. Six of these eight linear relationships from post-1976 were positive correlations, which is rather unusual as all corresponding linear relationships from other sites were inverse correlations. The increased number of significant linear relationships since LWR is similar to the increase observed at Red Head Rapids after CRD. There was only one year of data available for hardness, K, Na and Cl resulting in small sample size (8-9) and a limited range of flows (898-1590 m^3/s) although r values were quite high (0.66-0.88). It is unclear at present what role, if any, decreased flows and reversal of seasonal discharge patterns (Figure 10) have served in altering relationships between water chemistry and discharge.

5.0 SUMMARY

Significant linear relationships were evident between numerous water chemistry parameters and ln discharge at various sites within the CRD and LWR region. Sixty-four percent of these linear relationships were inverse correlations. In general, water chemistry parameters such as Ca, conductivity, alkalinity, Mg, hardness, TIC, TKN and SO_4 tended to be inversely correlated to discharge, ie. as ln discharge increased, concentration of these parameters declined in a linear fashion. Water chemistry parameters such as turbidity, color and NFR tended to be positively correlated and increased in a linear fashion as discharge increased. Only nitrate+nitrite concentrations did not exhibit a linear relationship at some location during either period. No parameters were linearly dependent on ln discharge at all sites. Linear relationships to ln discharge were most prevalent in conductivity, alkalinity, Ca and turbidity.

Figure 10. Discharge pattern for Cross Lake. Lines connect the monthly mean discharge data (m^3/s) from Bladder Rapids during 1968 - 1984. * = Annual mean discharge (m^3/s).



Water chemistry / water discharge relationships have been affected by CRD and LWR. Regressions expressed in this report support, to a limited extent, a correlation between changes in mean water quality values, reported by Playle and Williamson (1986), and altered discharge. Regression equations for Thompson provide fairly strong support of correlations between the reported changes in mean water quality values and development-related changes in discharge. However, regression equations for Cross Lake provide no evidence for such correlations. Nearly two-thirds of all significant linear relationships between water quality parameters and ln discharge occurred after CRD and LWR began. During the pre-development period slightly more than 3/4 (i.e. 77%) of the linear relationships were negative; whereas post-development there was a more equal distribution (57% were positive correlations). At sites along the Nelson River this shift was even more pronounced. The significance of these shifts to future water quality is uncertain. Use of simple linear regression analysis alone to predict future trends in water quality will be of limited value due to the changing nature of the relationships and involvement of other factors. A more complex approach such as principal component analysis or a model based on time series analysis would likely provide more accurate information.

Clearly, discharge has effects on many water quality parameters. These effects vary with location and time. This study has shown that alterations in discharge are reflected in the water chemistry/discharge relationship. This relationship is often linear in nature but may change with location and/or time. Lotic environments are not stable systems, they are constantly changing and evolving, even under pristine conditions. Anthropogenic activities will contribute to this change, potentially altering the rate of succession. Periods of drought and flood stages (i.e. natural cycles) will also influence water chemistry/discharge relationships. Monitoring programs permit assessment of trends, identification of interrelated parameters and possibly prediction of future impacts.

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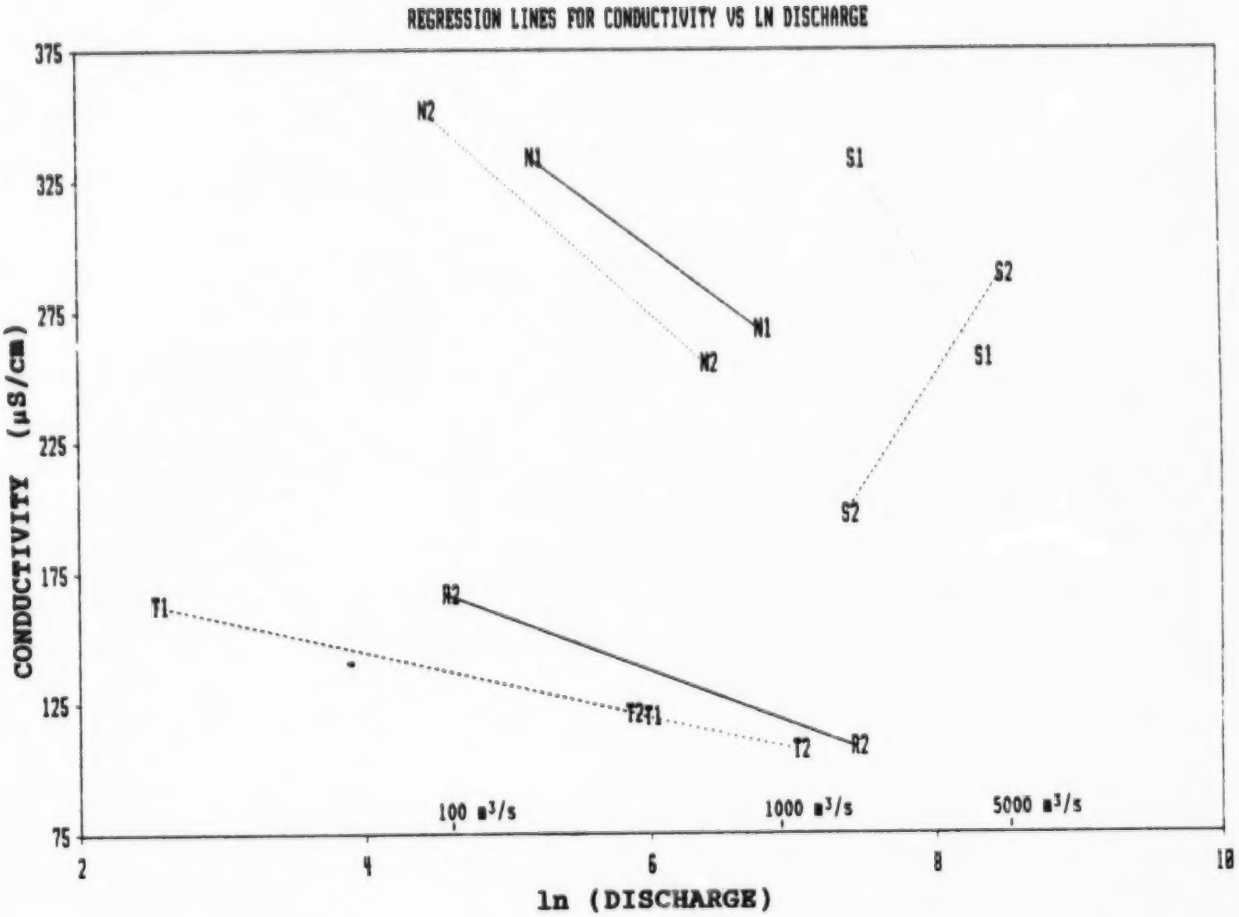
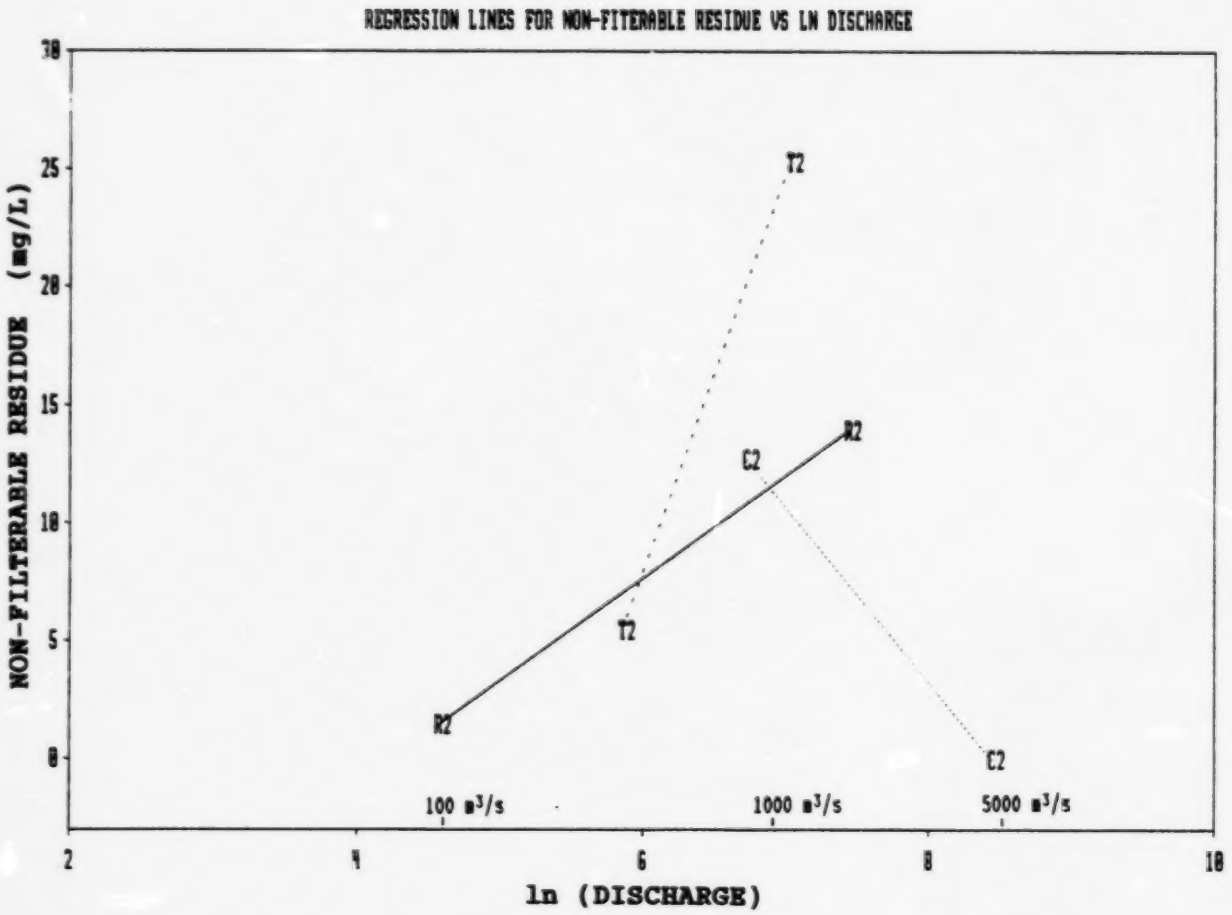
7.0 APPENDICES

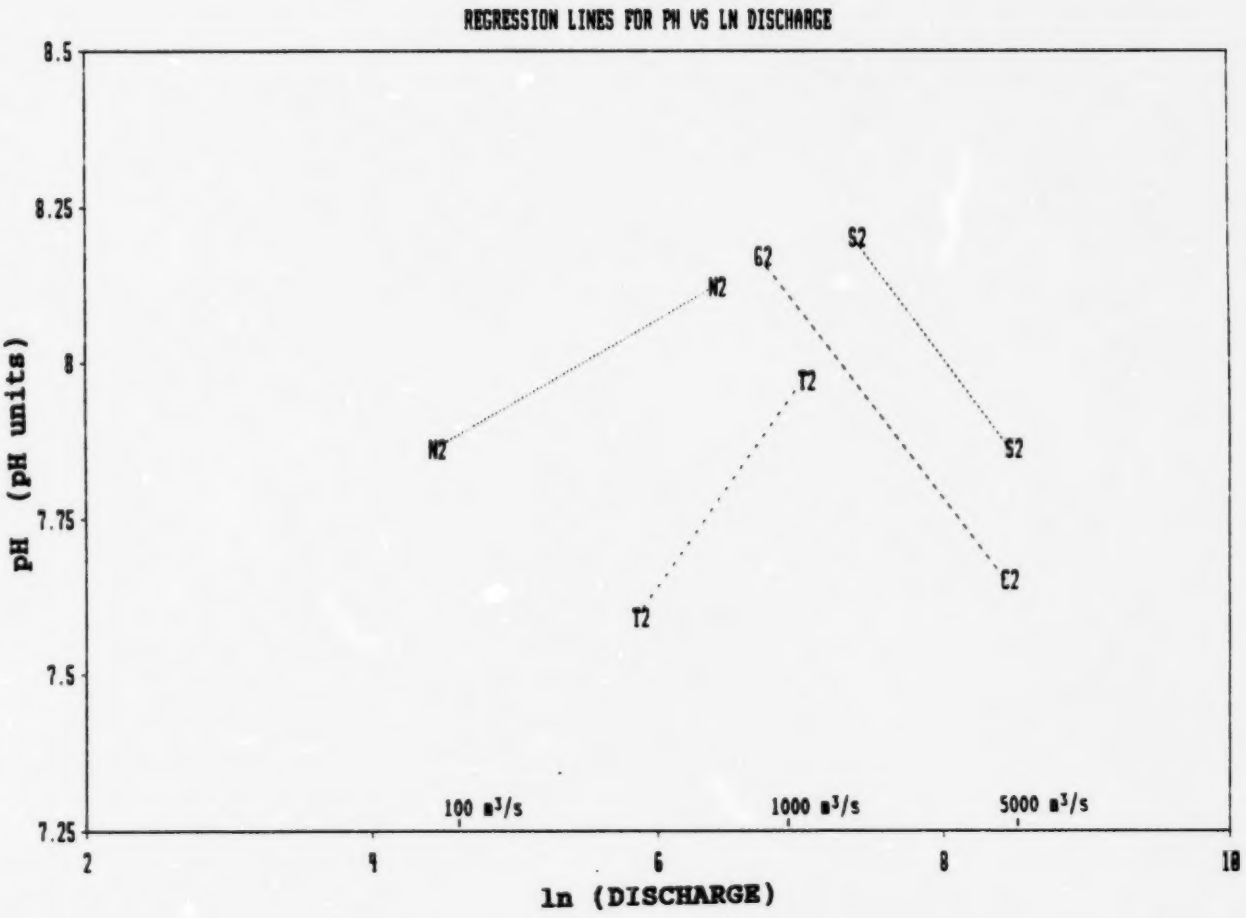
Appendix A.

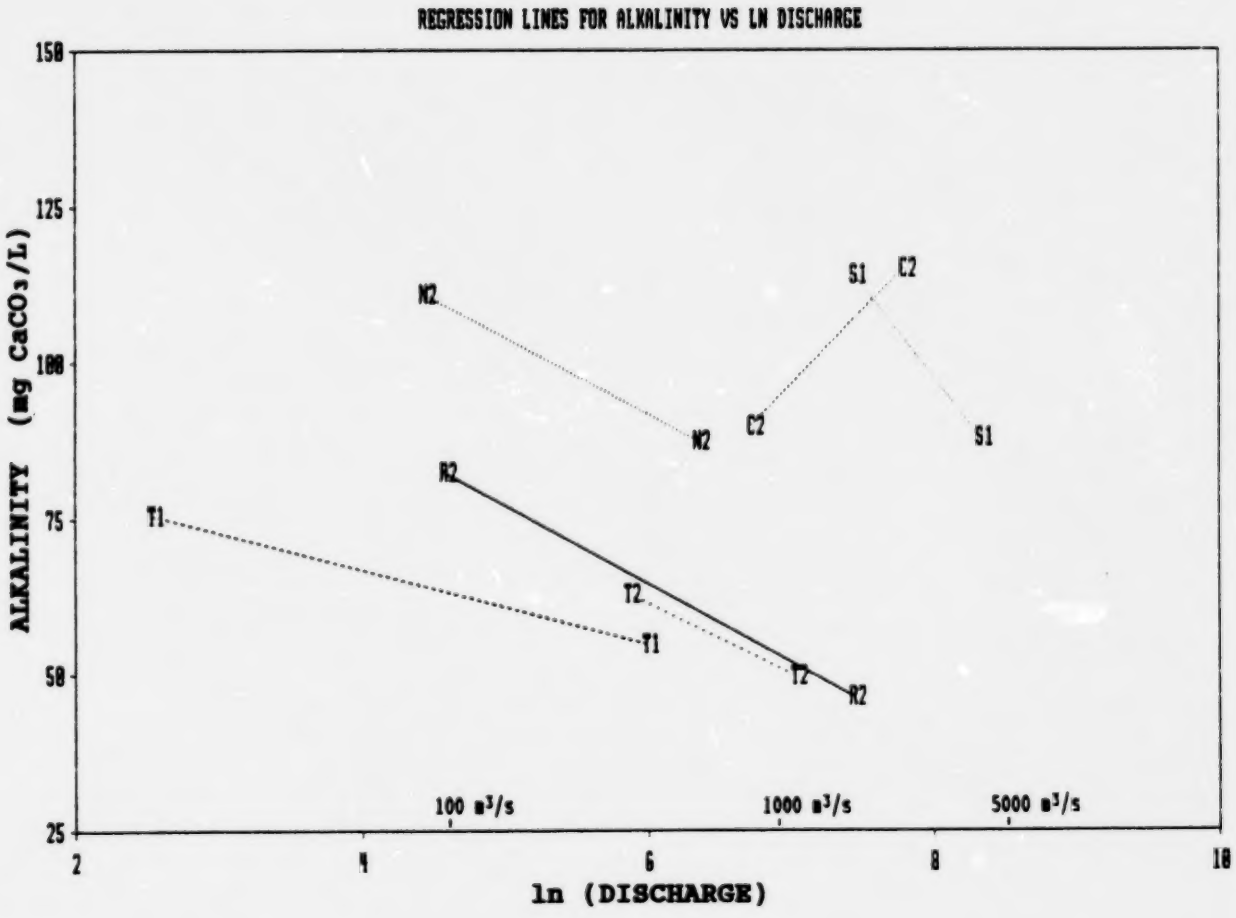
Graphs of statistically significant regression lines for water chemistry parameters vs ln discharge. Each graph is for a single parameter, at various locations. The location is represented by a letter code (as indicated below) and the numbers immediately following the letters indicate the period of record (1=pre-1976 & 2=post-1976).

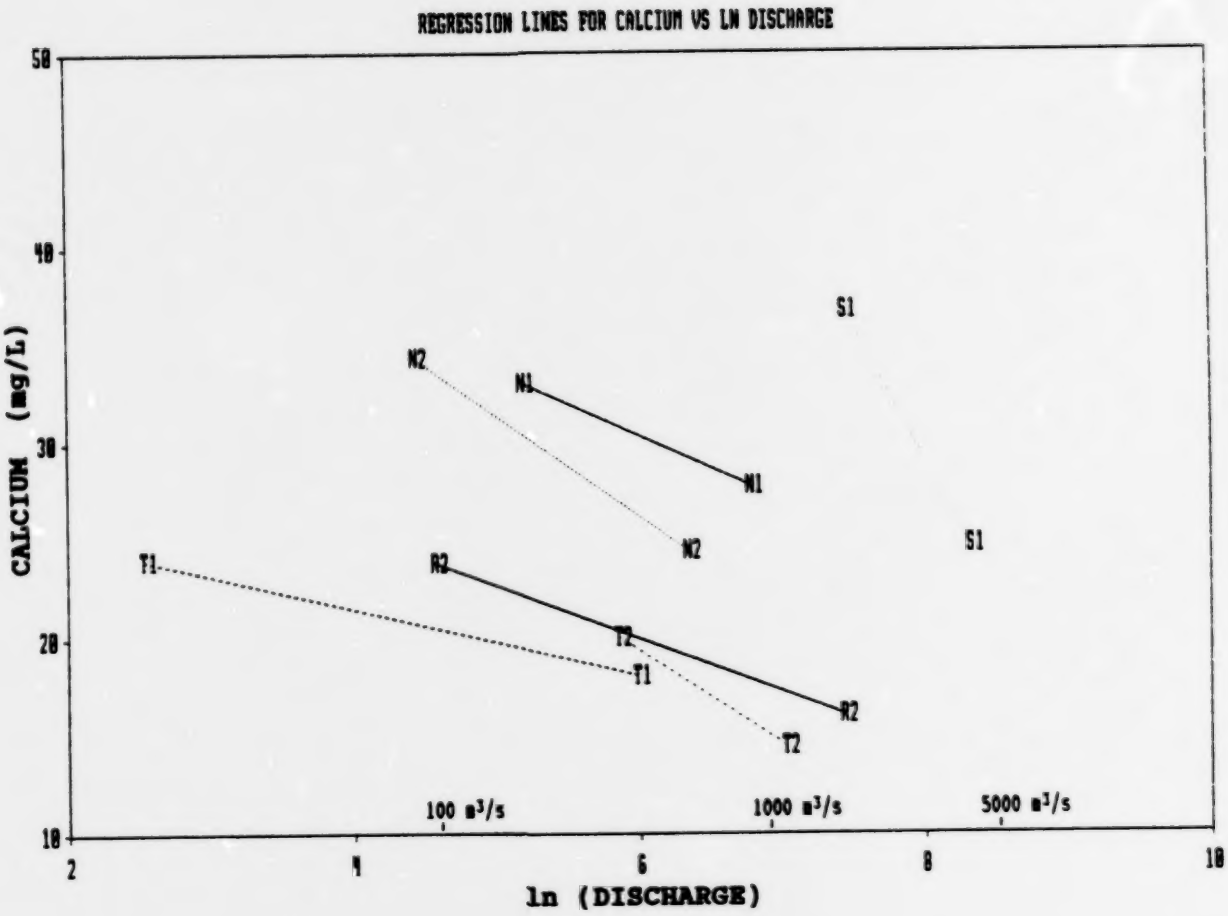
Code	Location	Code	Location
G	Granville Lake	T	Thompson
SIL	South Indian Lake	S	Split Lake
M	Missi Falls	N	Norway House
R	Red Head Rapids	C	Cross Lake

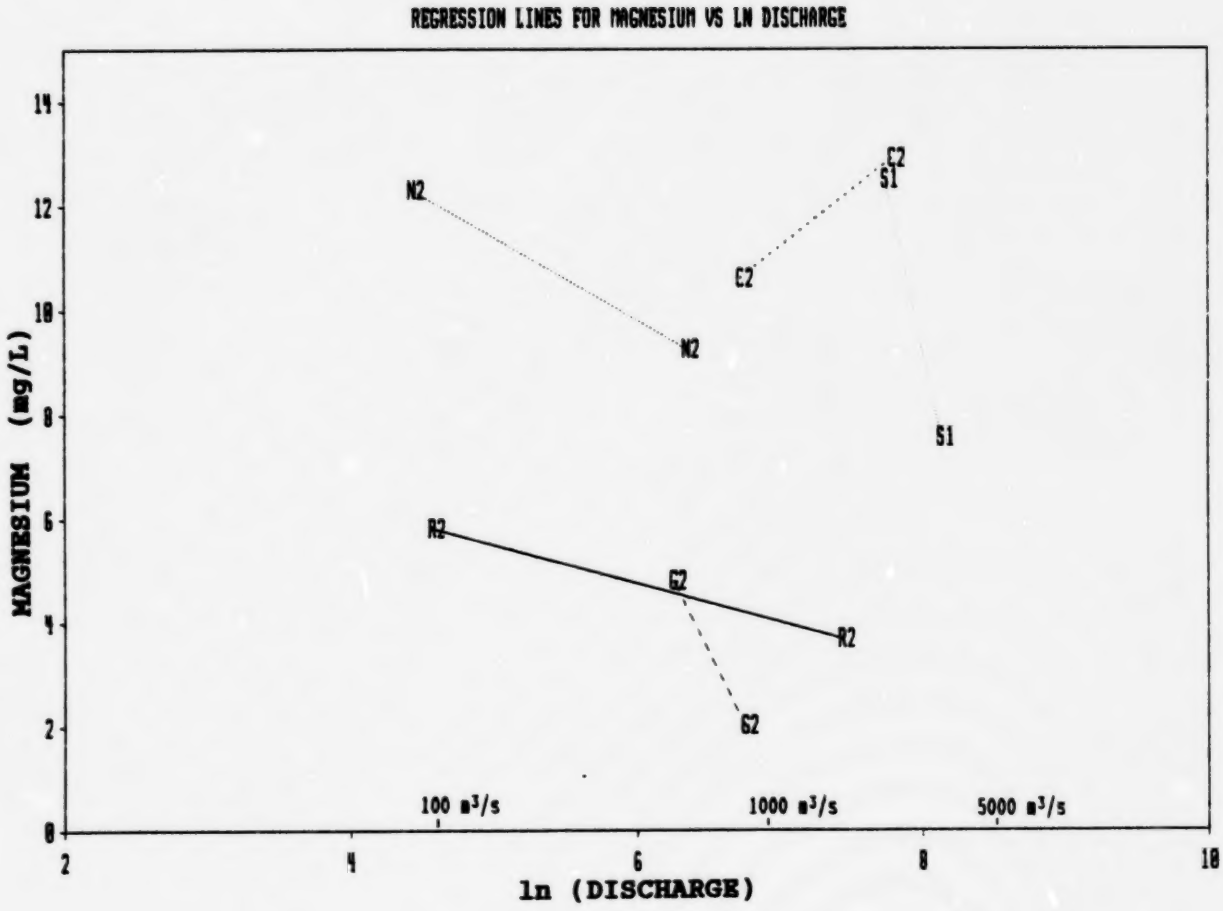

REGRESSION LINES FOR CONDUCTIVITY VS LN DISCHARGE
CONDUCTIVITY (µS/cm)
375
325
275
225
175
125
75
2
4
6
8
10
ln (DISCHARGE)
100 m³/s
1000 m³/s
5000 m³/s
N2
N1
S1
S2
T1
T2
R2

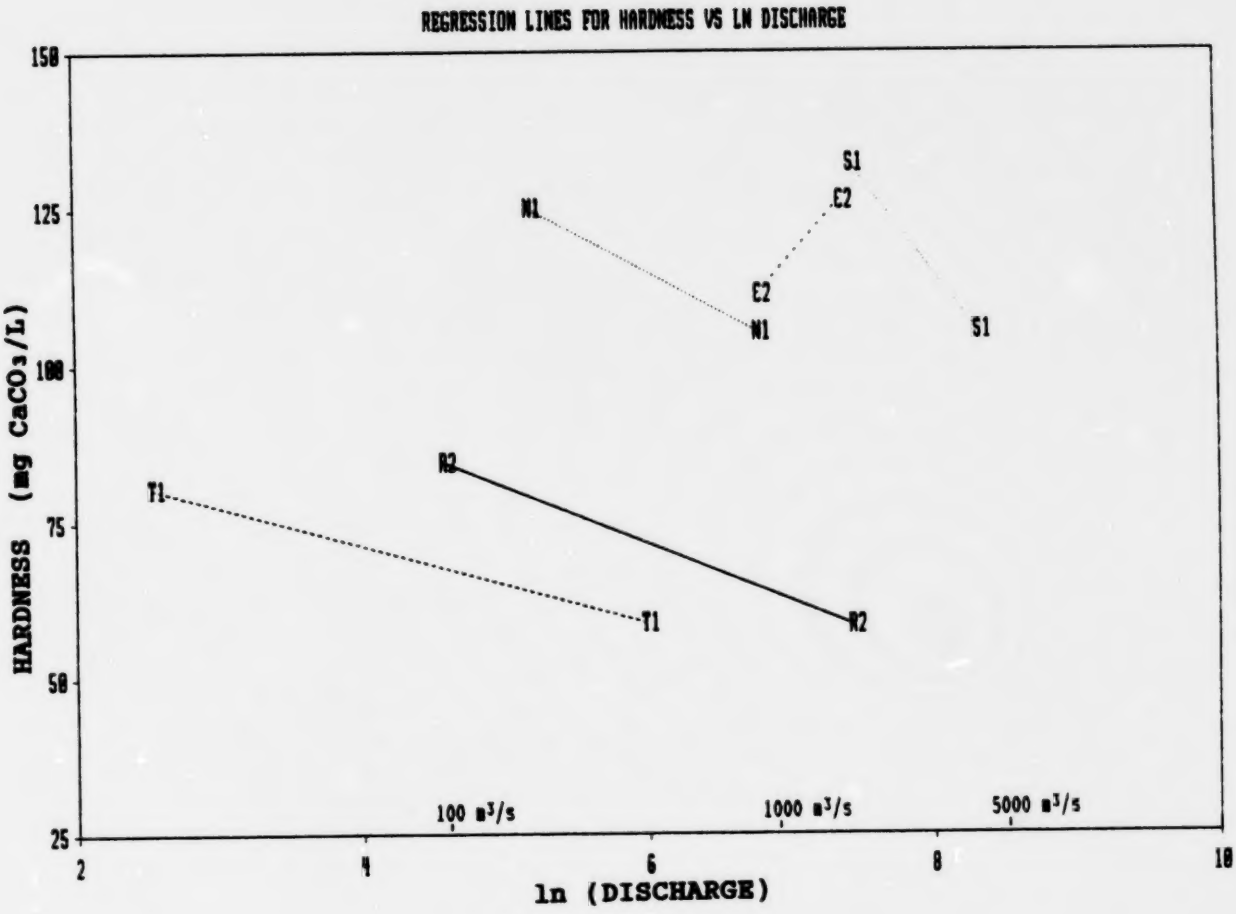

REGRESSION LINES FOR NON-FITERABLE RESIDUE VS LN DISCHARGE
NON-FILTERABLE RESIDUE (mg/L)
30
25
20
15
10
5
0
T2
R2
C2
T2
R2
C2
100 m³/s
1000 m³/s
5000 m³/s
2
4
6
8
10
ln (DISCHARGE)

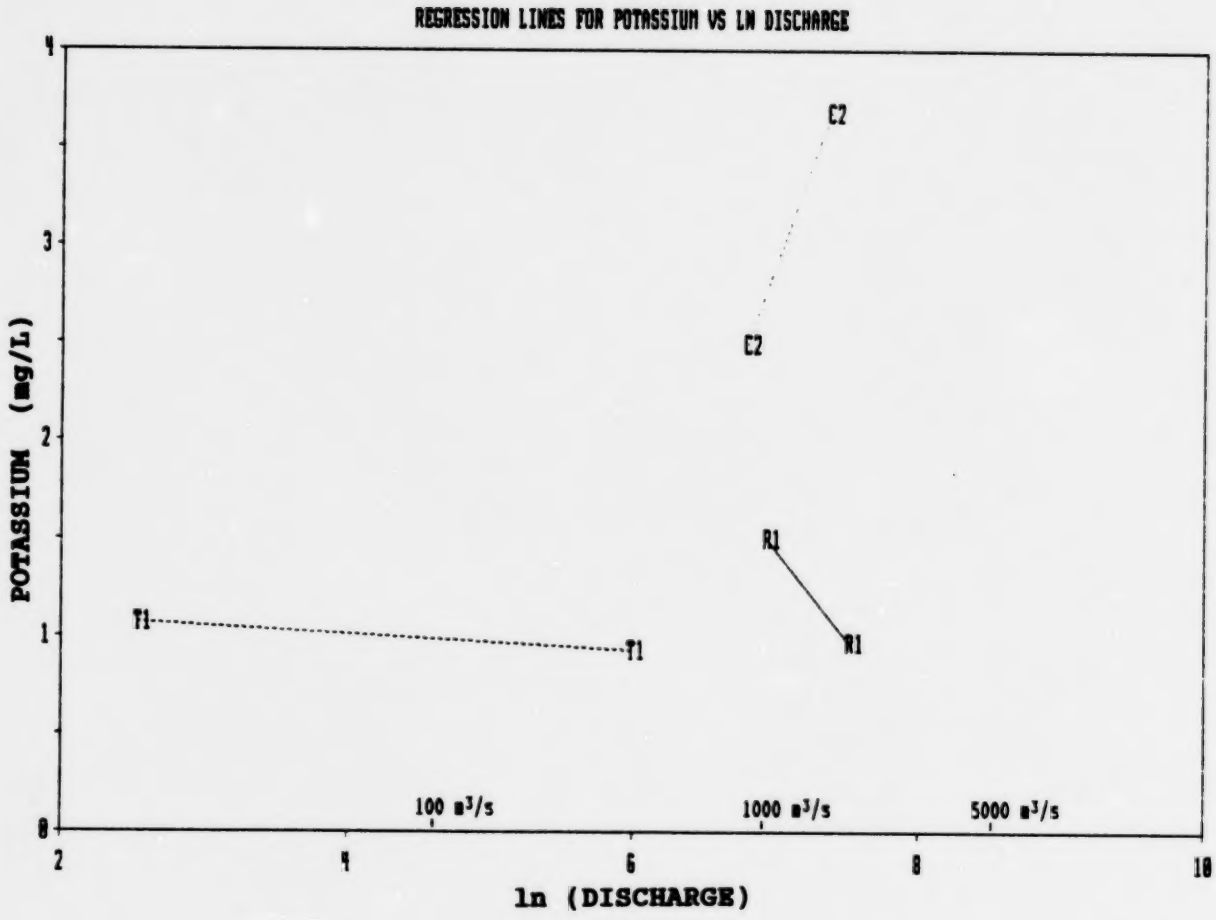

REGRESSION LINES FOR PH VS LN DISCHARGE
8.5
8.25
8
7.75
7.5
7.25
pH (pH units)
2
4
6
8
10
ln (DISCHARGE)
100 m³/s
1000 m³/s
5000 m³/s
N2
N2
G2
C2
S2
S2
T2
T2

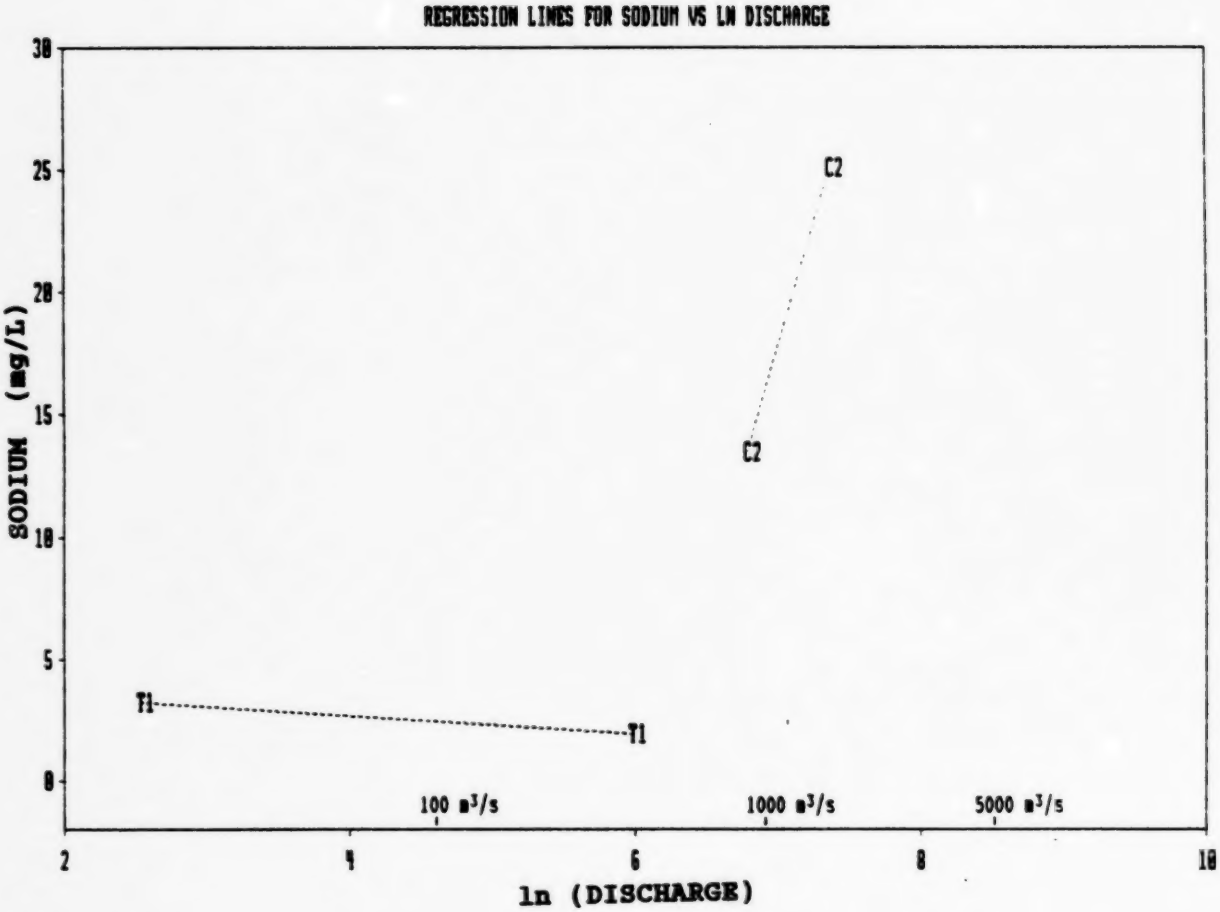

REGRESSION LINES FOR ALKALINITY VS LN DISCHARGE
ALKALINITY (mg CaCO3/L)
150
125
100
75
50
25
2
4
6
8
10
ln (DISCHARGE)
100 m3/s
1000 m3/s
5000 m3/s
N2
N2
C2
S1
C2
S1
R2
R2
T1
T1
T2
T2

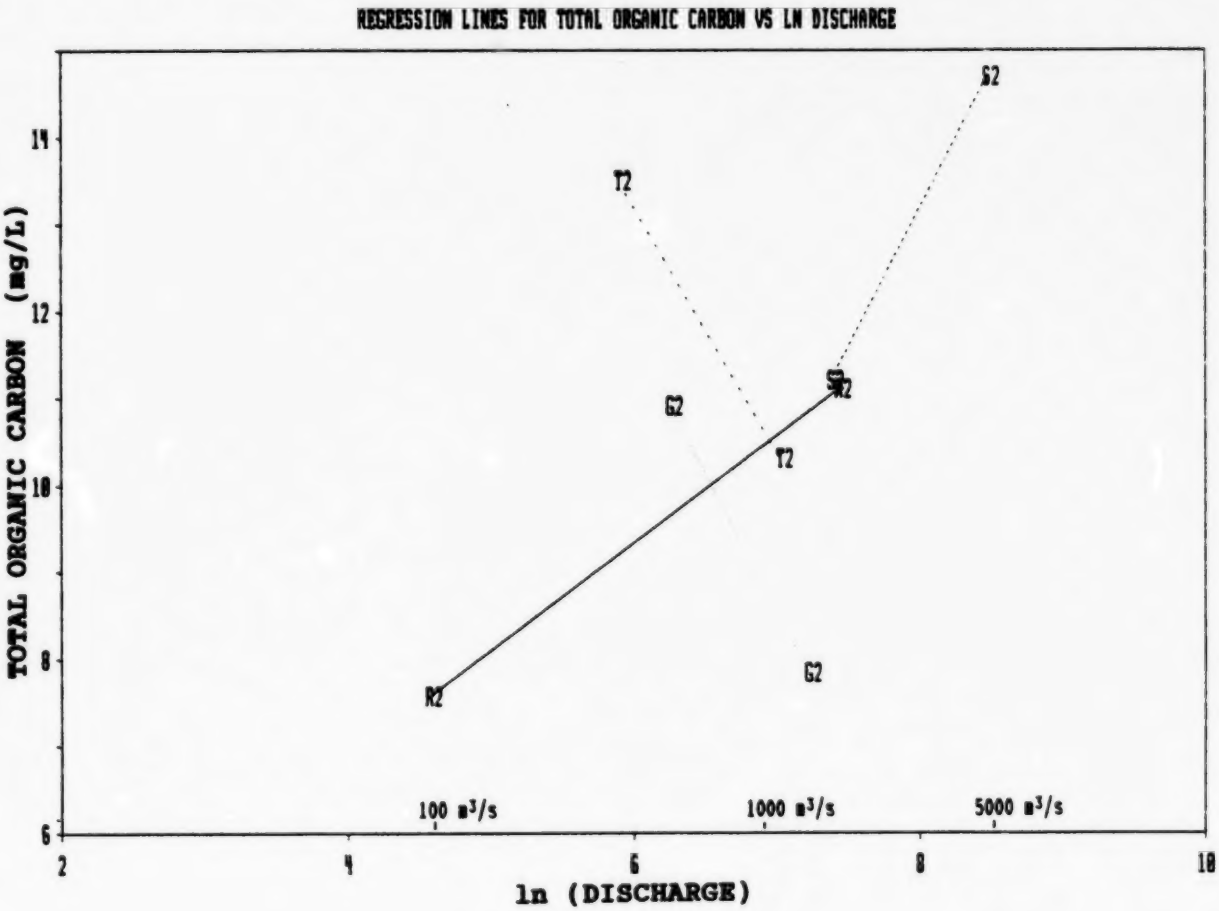

REGRESSION LINES FOR CALCIUM VS LN DISCHARGE
CALCIUM (mg/L)
50
40
30
20
10
2
4
6
8
10
ln (DISCHARGE)
100 m³/s
1000 m³/s
5000 m³/s
S1
S1
N2
N1
N1
N2
T1
R2
T2
T1
R2
T2

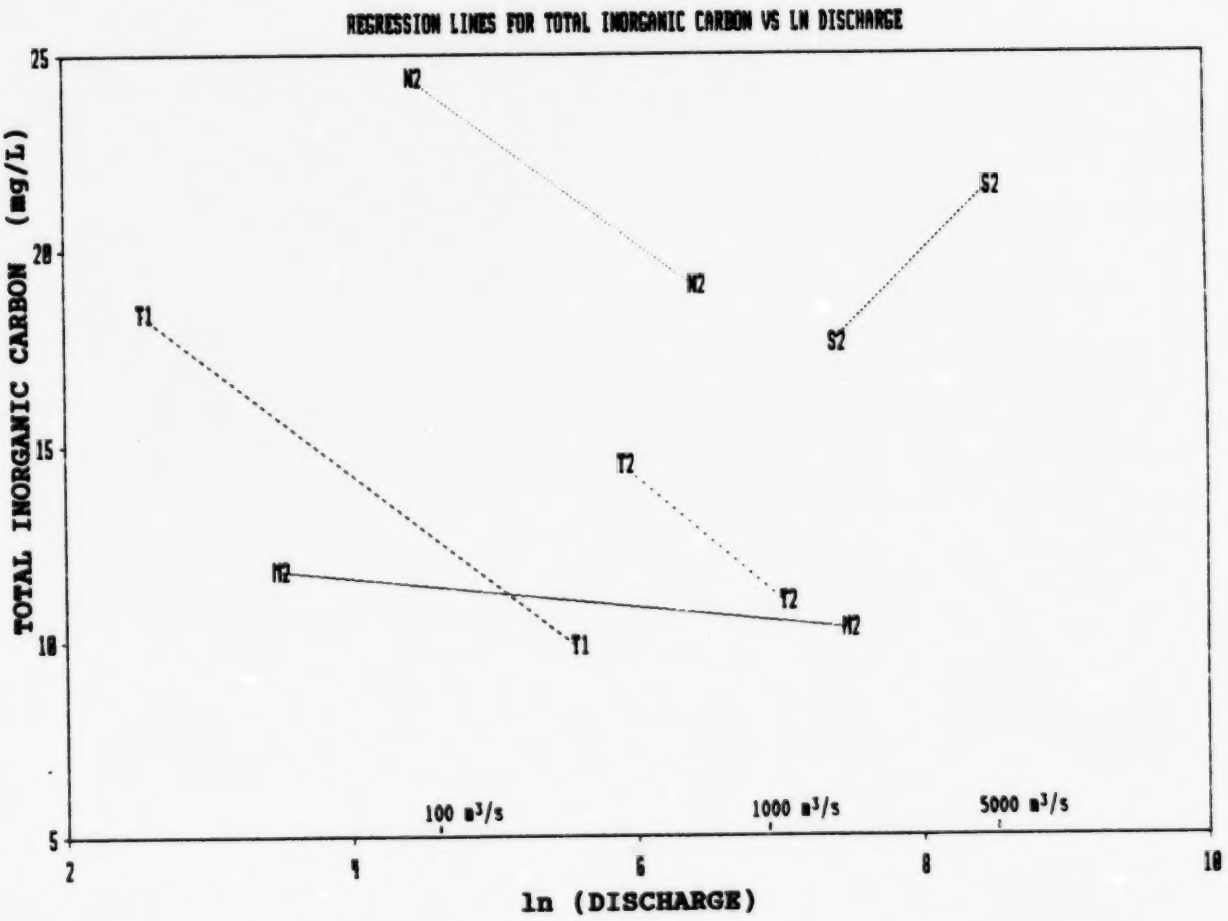

REGRESSION LINES FOR MAGNESIUM VS LN DISCHARGE
MAGNESIUM (mg/L)
ln (DISCHARGE)
14
12
10
8
6
4
2
0
2
4
6
8
10
100 m³/s
1000 m³/s
5000 m³/s
N2
N2
C2
S1
C2
S1
R2
R2
G2
G2

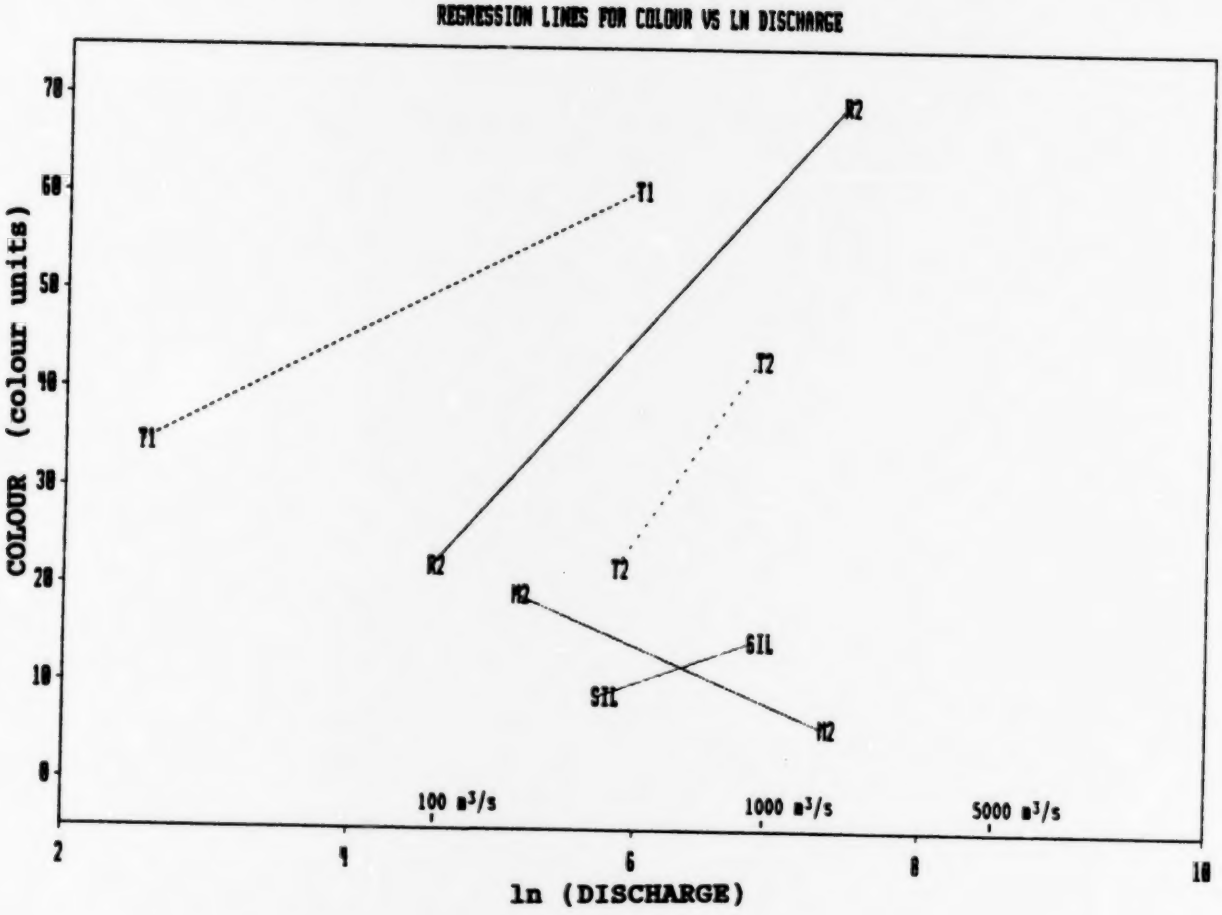

REGRESSION LINES FOR HARDNESS VS LN DISCHARGE
HARDNESS (mg CaCO3/L)
150
125
100
75
50
25
2
4
6
8
10
ln (DISCHARGE)
100 m3/s
1000 m3/s
5000 m3/s
S1
E2
N1
E2
N1
S1
N2
T1
T1
N2

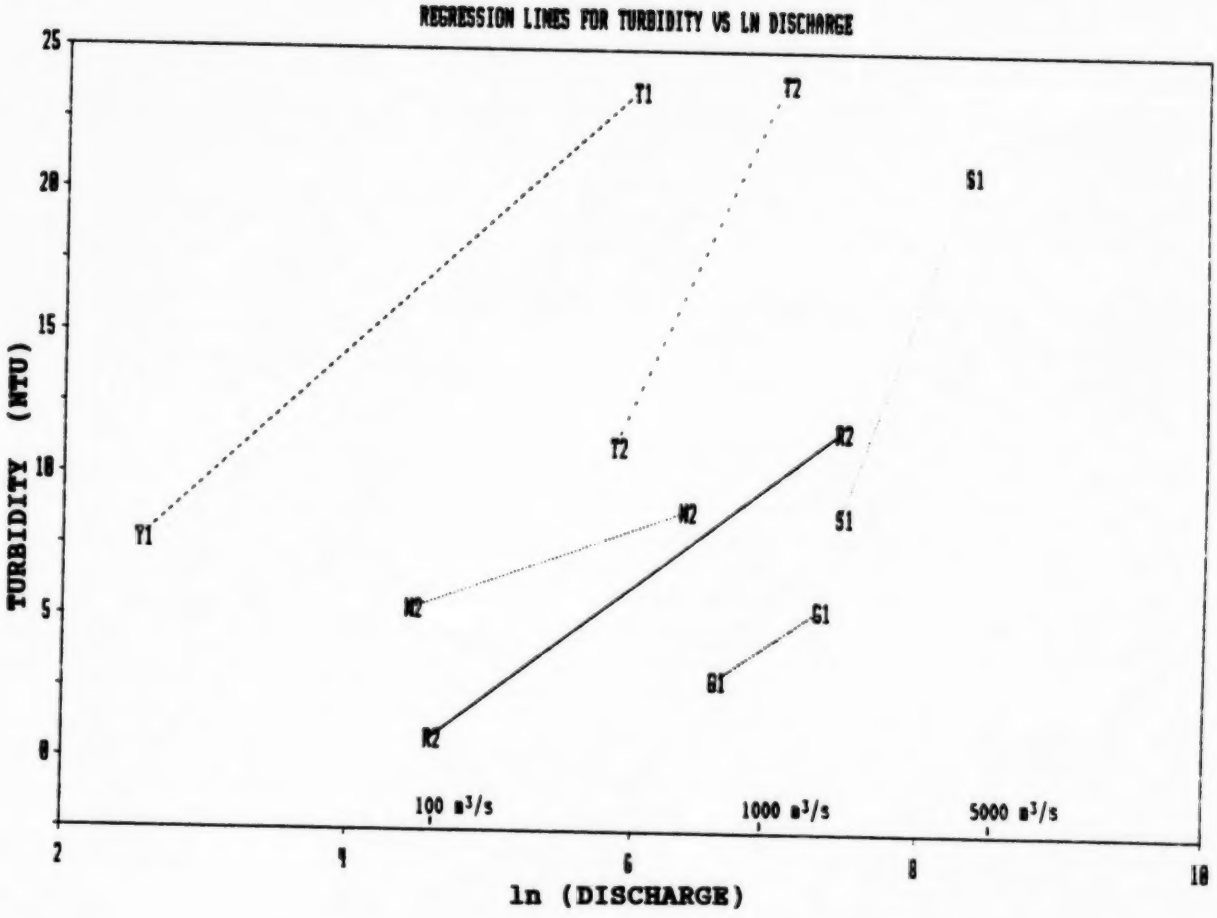

REGRESSION LINES FOR POTASSIUM VS LN DISCHARGE
POTASSIUM (mg/L)
ln (DISCHARGE)
0
1
2
3
4
2
4
6
8
10
C2
C2
R1
R1
T1
T1
100 m³/s
1000 m³/s
5000 m³/s

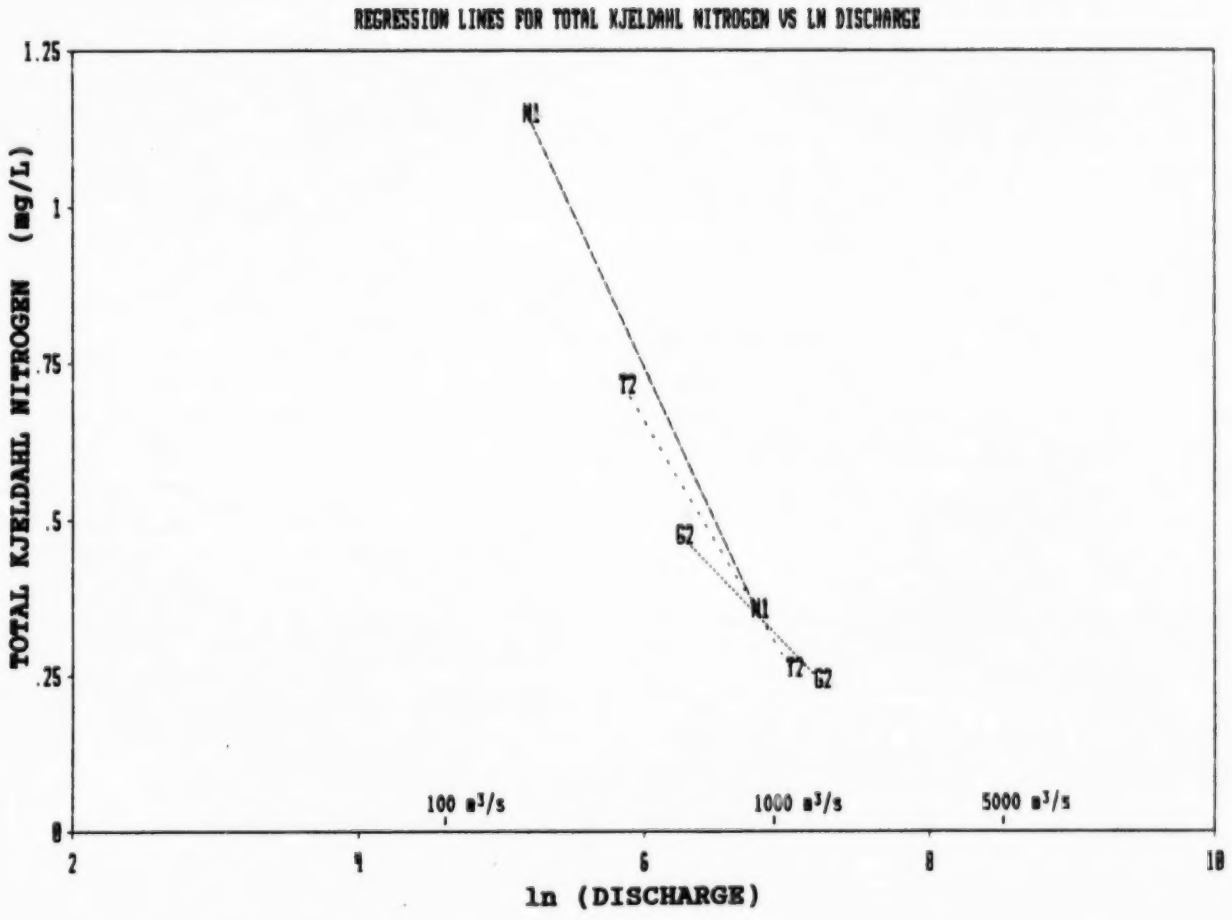

REGRESSION LINES FOR SODIUM VS LN DISCHARGE
SODIUM (mg/L)
30
25
20
15
10
5
0
C2
C2
T1
T1
100 m³/s
1000 m³/s
5000 m³/s
2
4
6
8
10
ln (DISCHARGE)

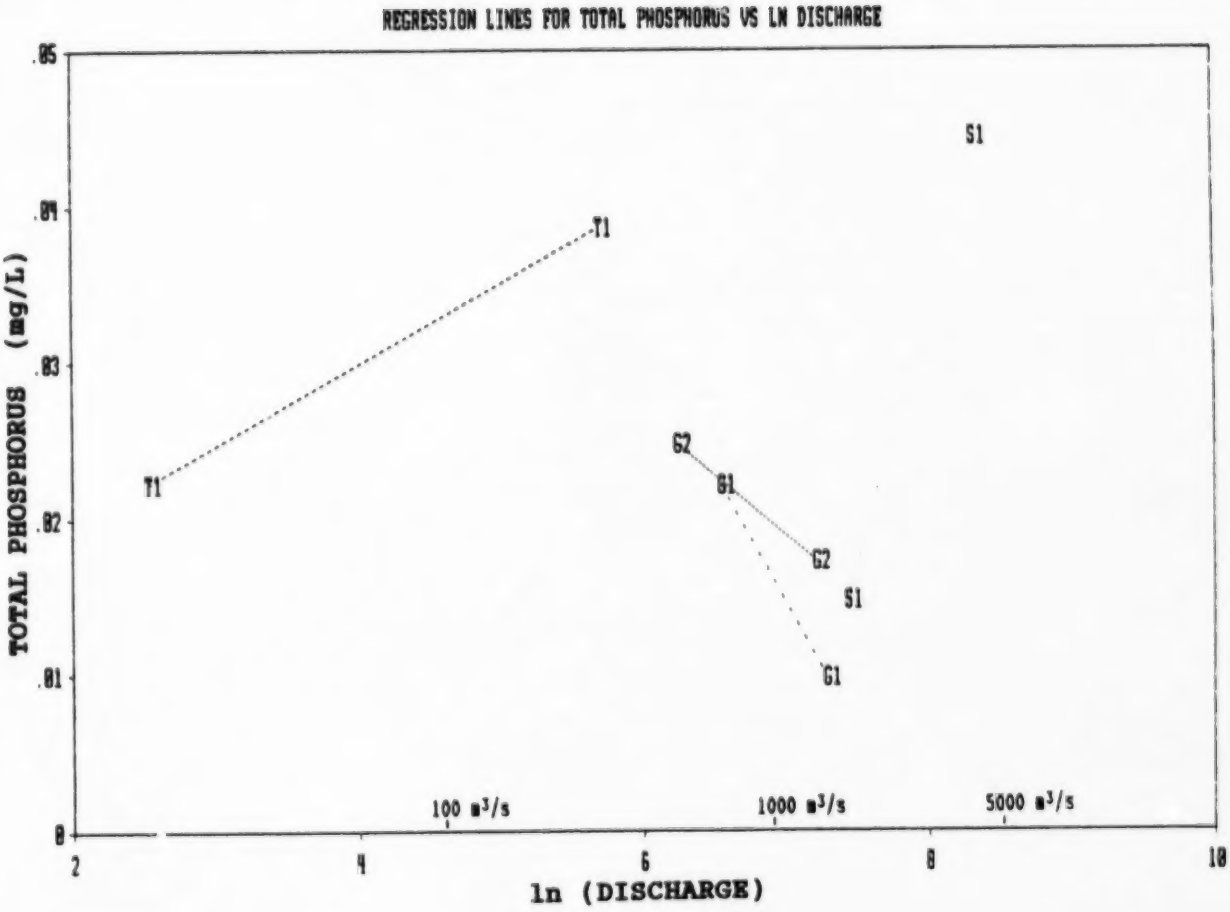

REGRESSION LINES FOR TOTAL ORGANIC CARBON VS LN DISCHARGE
TOTAL ORGANIC CARBON (mg/L)
14
12
10
8
6
2
4
6
8
10
ln (DISCHARGE)
100 m³/s
1000 m³/s
5000 m³/s
T2
G2
R2

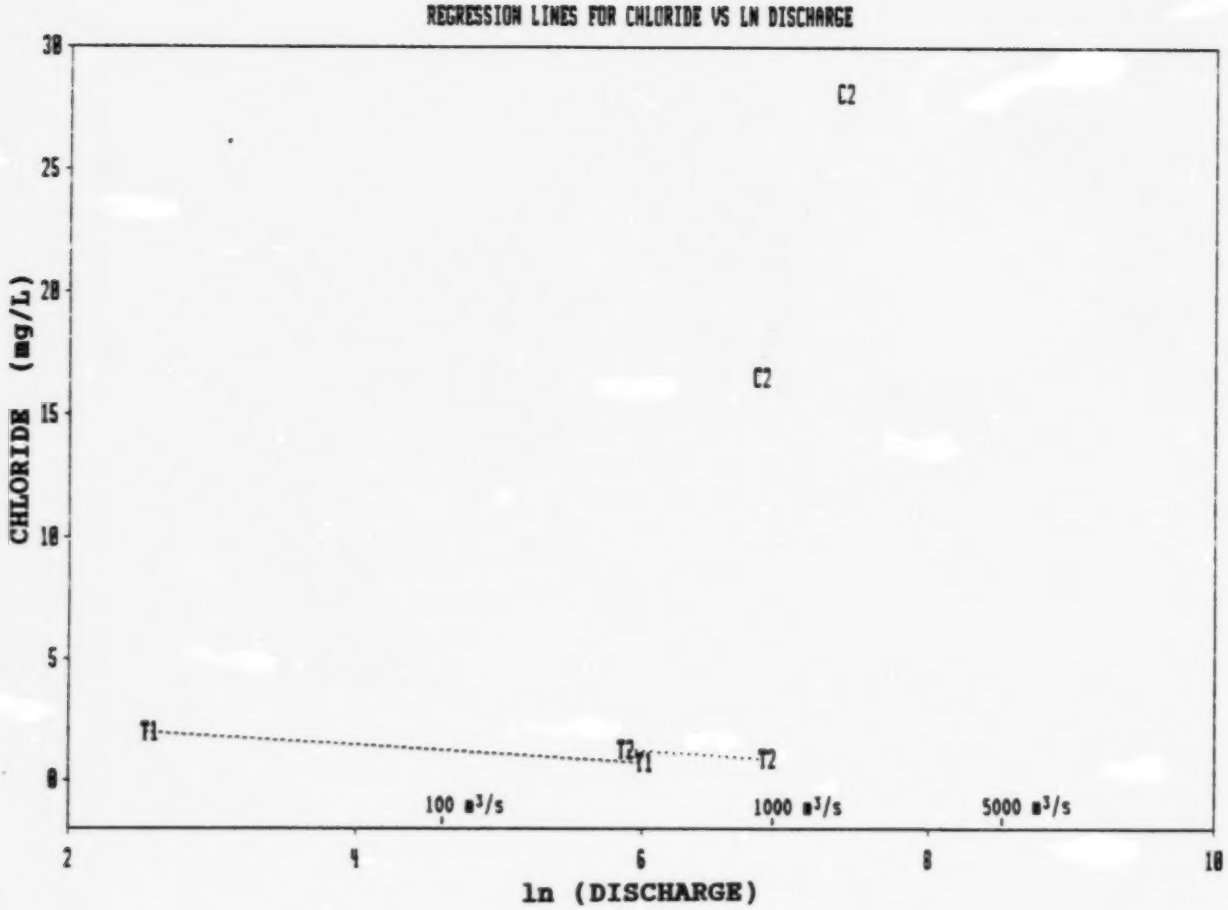

REGRESSION LINES FOR TOTAL INORGANIC CARBON VS LN DISCHARGE
TOTAL INORGANIC CARBON (mg/L)
25
20
15
10
5
N2
N2
S2
S2
T1
T2
T2
N2
N2
T1
100 m3/s
1000 m3/s
5000 m3/s
2
4
6
8
10
ln (DISCHARGE)

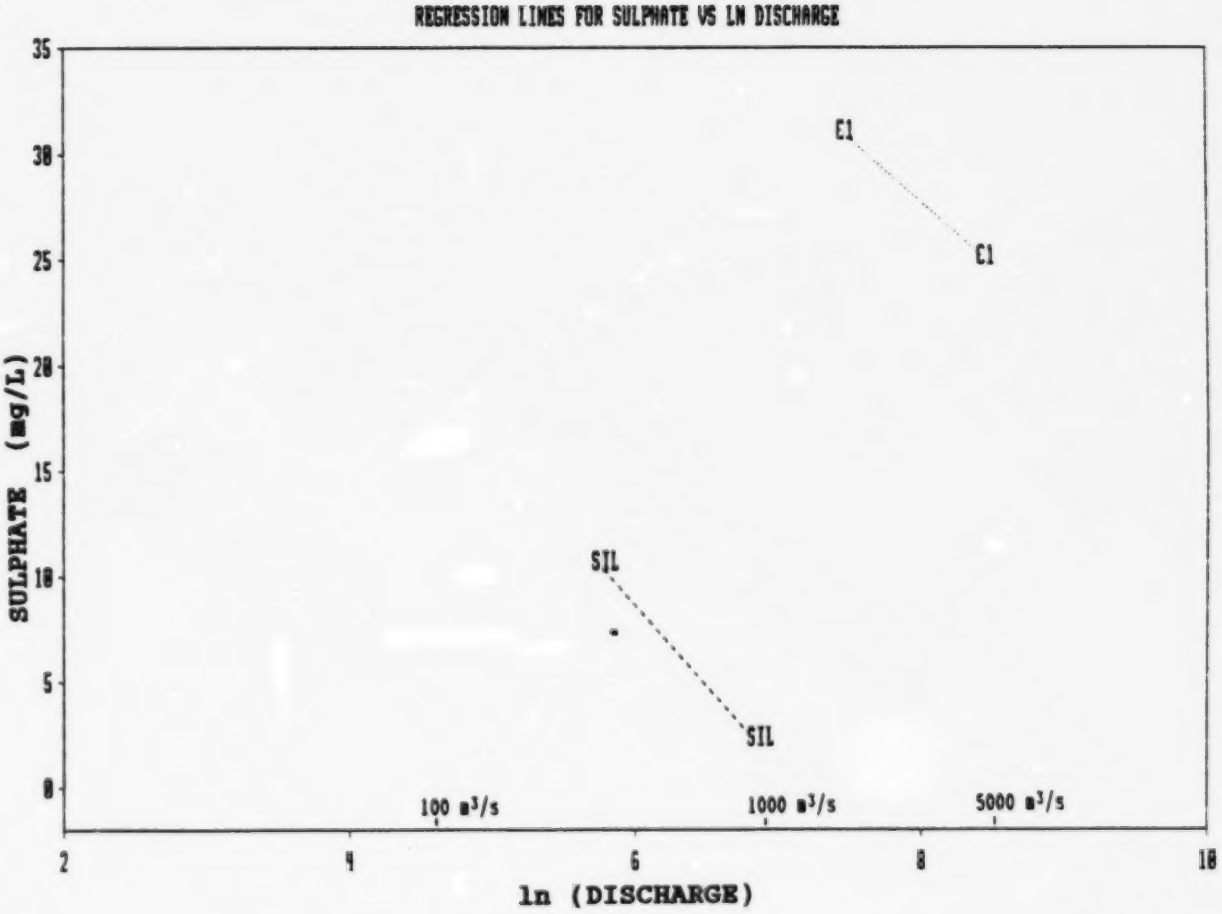

REGRESSION LINES FOR COLOUR VS LN DISCHARGE
COLOUR (colour units)
70
60
50
40
30
20
10
0
R2
T1
T1
T2
T2
R2
M2
GIL
SIL
M2
100 m³/s
1000 m³/s
5000 m³/s
2
4
6
8
10
ln (DISCHARGE)


REGRESSION LINES FOR TURBIDITY VS LN DISCHARGE
TURBIDITY (NTU)
25
20
15
10
5
0
T1
T2
S1
M2
G1
100 m³/s
1000 m³/s
5000 m³/s
2
4
6
8
10
ln (DISCHARGE)


REGRESSION LINES FOR TOTAL KJELDAHL NITROGEN VS LN DISCHARGE
TOTAL KJELDAHL NITROGEN (mg/L)
1.25
1
.75
.5
.25
0
N1
T2
G2
N1
T2
G2
100 m³/s
1000 m³/s
5000 m³/s
2
4
6
8
10
ln (DISCHARGE)


REGRESSION LINES FOR TOTAL PHOSPHORUS VS LN DISCHARGE
TOTAL PHOSPHORUS (mg/L)
.85
.84
.83
.82
.81
0
T1
T1
G2
G1
G2
S1
S1
100 m3/s
1000 m3/s
5000 m3/s
2
4
6
8
10
ln (DISCHARGE)


REGRESSION LINES FOR CHLORIDE VS LN DISCHARGE
CHLORIDE (mg/L)
30
25
20
15
10
5
0
C2
C2
T1
T2
T1
T2
100 m³/s
1000 m³/s
5000 m³/s
2
4
6
8
10
ln (DISCHARGE)


REGRESSION LINES FOR SULPHATE VS LN DISCHARGE
SULPHATE (mg/L)
35
30
25
20
15
10
5
0
C1
C1
SIL
SIL
100 m³/s
1000 m³/s
5000 m³/s
2
4
6
8
10
ln (DISCHARGE)

Appendix B.

Summary tables of monthly and annual mean discharge (m^3/s), annual extremes and total discharge for all locations.

Table B1. Monthly and annual mean discharge (m^3/s), annual extremes and total discharge for the Churchill River at Granville Falls.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN	MIN. FLOW	DATE mmdd	MAX. FLOW	DATE mmdd	TOT DIS m^3x10^9
1955	841	714	680	704	1020	1130	1090	958	822	726	765	816	856	680	03/01	1170	05/29	27.0
1956	776	722	668	634	697	794	638	564	539	537	535	535	636	521	09/27	810	06/01	20.1
1957	547	561	558	547	694	846	816	880	758	706	673	663	688	547	01/01	903	08/14	21.7
1958	665	666	652	657	792	894	927	881	817	879	814	775	786	637	04/11	934	07/11	24.8
1959	738	690	644	622	770	1140	1420	1340	1200	1070	958	821	953	620	04/13	1450	07/14	30.1
1960	732	700	688	678	779	1200	1480	1520	1290	1140	994	847	1010	668	03/01	1560	08/01	31.8
1961	771	715	709	720	862	1080	1010	830	691	661	706	690	788	643	09/27	1100	06/11	24.9
1962	693	708	712	697	964	1340	1090	905	833	793	757	726	852	685	01/01	1370	06/01	26.9
1963	728	743	766	767	912	1000	1040	1080	939	923	840	778	878	725	01/01	1180	07/29	27.7
1964	736	723	721	781	850	882	719	791	936	1080	1010	920	846	665	06/31	1100	10/10	26.8
1965	863	823	784	764	977	1120	1020	953	931	964	929	876	917	759	04/21	1160	06/01	28.9
1966	798	778	765	813	873	1010	1060	917	777	668	656	651	814	646	11/24	1110	07/01	25.7
1967	655	681	700	699	708	919	947	912	811	676	632	661	751	629	11/03	968	06/19	23.7
1968	686	729	767	744	864	836	732	658	669	735	735	706	738	637	08/24	898	06/03	23.4
1969	708	732	719	731	850	785	703	644	833	923	839	759	769	637	08/12	934	10/13	24.3
1970	729	713	706	702	796	861	1010	996	873	799	755	737	807	697	03/25	1060	07/21	25.5
1971	722	683	570	523	663	720	738	1040	1240	1290	1100	940	854	501	04/16	1330	10/12	26.9
1972	902	887	871	853	1110	1200	1100	962	852	911	900	854	950	824	09/21	1220	06/17	30.1
1973	848	844	828	824	940	995	918	879	899	859	839	838	876	816	04/12	1020	05/23	27.6
1974	815	800	821	849	1130	1240	1420	1440	1400	1310	1150	1040	1120	793	02/19	1480	07/24	35.3
1975	940	896	932	924	1120	1270	1160	1140	1120	1100	961	814	1030	784	12/25	1290	06/08	32.5
1976	790	813	804	811	748	686	998	1130	1160	1260	1200	987	950	660	06/14	1300	10/27	30.0
1977	897	879	876	909	1030	1190	1420	1460	1370	1080	918	858	1070	847	12/20	1480	07/22	33.9
1978	857	878	860	814	861	881	924	873	853	1040	1130	994	914	801	04/21	1210	10/30	28.8
1979	918	888	903	881	937	1050	928	776	696	791	909	899	881	685	09/21	1070	06/18	27.8
1980	903	887	888	905	899	720	693	706	810	---	---	---	---	684	07/03	975	05/03	---
1981	---	820	777	751	822	762	664	580	---	---	---	---	---	---	---	869	05/20	---
1982	613	585	558	513	683	662	633	523	546	507	496	614	578	468	11/03	730	05/21	18.2
1983	689	677	654	632	712	680	640	591	560	859	819	764	690	500	09/12	892	10/15	21.8
1984	738	745	733	807	853	781	790	699	650	622	688	722	736	596	10/16	942	05/02	23.3

Table B2. Monthly and annual mean discharge (m^3/s), annual extremes and total discharge for the Churchill River at South Bay, SIL.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN	MIN. FLOW	DATE mmdd	MAX. FLOW	DATE mmdd	TOT_DIS $m^3 \times 10^9$
1976	---	---	---	---	---	256	300	125	218	285	291	284	---	---	---	---	---	---
1977	281	295	306	366	10	-185	279	607	869	898	786	726	436	-367	07/04	1120	11/01	---
1978	782	760	854	737	547	770	849	666	738	754	698	707	738	-343	04/01	1740	04/08	---
1979	692	705	787	951	707	690	523	746	712	795	782	801	741	447	07/16	1390	04/19	---
1980	810	820	837	1040	718	810	812	826	646	699	773	773	797	447	11/01	1480	04/25	---
1981	802	824	821	819	753	882	939	895	759	553	539	558	762	376	11/04	1210	02/27	---
1982	543	545	552	565	520	404	683	743	862	811	773	774	648	344	06/30	879	09/18	---
1983	802	689	606	604	545	739	839	832	858	867	912	850	762	495	03/10	1040	11/13	---
1984	850	866	851	991	809	888	901	756	596	682	766	799	813	550	11/10	1300	04/26	---

Table B3. Monthly and annual mean discharge (m^3/s), annual extremes and total discharge for the Churchill River at Missi Falls.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN	MIN. FLOW	DATE mmdd	MAX. FLOW	DATE mmdd	TOT_DIS m^3x10^9
1976	955	694	778	---	1120	463	322	413	741	1180	1100	985	---	164	07/26	1480	05/23	---
1977	822	736	656	765	1150	1550	1180	978	823	569	432	195	821	170	12/09	1740	06/08	---
1978	173	175	175	177	424	730	382	772	469	627	543	498	429	170	01/01	1510	08/27	---
1979	439	231	175	175	175	406	789	304	53	104	113	113	257	30	10/03	855	07/07	---
1980	113	113	113	154	117	283	259	533	612	475	189	232	266	33	07/29	1440	08/27	---
1981	207	175	173	162	109	35	35	34	47	168	135	120	117	33	09/15	231	01/01	---
1982	120	113	112	98	42	65	218	36	20	111	113	87	95	17	07/23	435	07/08	---
1983	76	56	44	44	44	24	18	16	174	343	122	120	90	16	08/29	522	09/22	---
1984	119	117	91	48	37	20	16	16	32	152	135	114	75	15	07/23	171	10/11	---

Table B4. Monthly and annual mean discharge (m^3/s), annual extremes and total discharge for the lower Churchill River at Red Head Rapids.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN	MIN. FLOW	DATE mmdd	MAX. FLOW	DATE mmdd	TOT_DIS m^3x10^9
1972	1480	1300	1140	---	---	---	1840	1670	1750	---	---	---	---	---	---	---	---	---
1973	---	1100	1120	---	---	---	1300	1030	942	1010	1030	1130	---	799	11/07	---	---	---
1974	1150	1130	1070	1020	1120	1420	1520	1680	1650	1610	1540	1420	1360	1020	04/10	1720	08/09	43.0
1975	1270	1150	1090	1090	1240	1640	1780	1760	1690	1590	1390	1100	1400	988	12/31	1890	06/30	44.2
1976	885	791	775	1110	1360	1230	672	657	832	1300	1250	1080	995	634	07/10	1850	06/05	31.5
1977	750	717	702	789	1570	1860	1690	1250	1050	838	499	277	1000	210	12/20	1980	07/02	31.6
1978	208	206	203	206	354	1150	780	1140	1290	1000	747	512	651	202	03/25	1850	09/05	20.5
1979	400	309	237	186	430	1030	1110	---	---	---	212	163	---	153	12/31	1180	07/17	---
1980	149	152	158	274	491	620	733	821	1650	888	582	345	572	146	01/09	2220	09/08	18.1
1981	288	226	212	204	---	525	235	151	117	260	204	151	---	107	09/30	---	---	---
1982	137	130	124	119	---	701	655	285	309	328	277	220	---	---	---	---	---	---
1983	178	134	105	100	229	---	327	---	---	903	463	265	---	99	05/06	---	---	---
1984	201	177	157	---	---	---	---	---	92	151	197	157	---	---	---	---	---	---

Table B5. Monthly and annual mean discharge (m^3/s), annual extremes and total discharge for the Burntwood River near Thompson.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN	MIN. FLOW	DATE mmdd	MAX. FLOW	DATE mmdd	TOT_DIS $m^3 \times 10^9$
1957	---	---	---	---	---	---	---	---	---	64	50	37	---	---	---	---	--	---
1958	28	22	22	45	132	158	118	88	81	131	120	75	85	20	02/13	168	06/13	2.7
1959	41	32	16	16	213	460	342	204	185	161	119	71	156	12	04/08	496	06/19	4.9
1960	38	27	25	22	141	410	238	107	58	33	24	14	95	12	12/21	459	06/08	3.0
1961	9	8	8	9	69	158	108	74	45	36	28	24	48	8	03/21	164	06/11	1.5
1962	20	18	15	13	264	440	268	127	76	60	48	37	116	13	04/24	504	05/29	3.7
1963	28	22	19	25	242	296	199	125	124	120	134	71	118	18	04/04	331	05/31	3.7
1964	36	25	21	21	196	224	119	135	239	222	143	85	122	17	04/10	277	09/22	3.9
1965	56	41	29	24	254	408	279	137	95	98	86	64	131	20	04/22	450	06/12	4.1
1966	50	40	29	26	176	508	380	188	99	52	29	22	133	20	12/31	578	06/19	4.2
1967	20	19	17	15	76	298	230	146	69	42	34	29	83	14	04/27	311	06/11	2.6
1968	28	24	20	21	191	260	182	119	98	167	158	107	115	18	04/03	297	05/26	3.6
1969	67	36	25	56	156	168	124	80	182	369	266	156	141	21	03/29	416	10/15	4.4
1970	81	54	36	26	139	267	352	205	127	100	152	117	139	21	04/16	396	07/08	4.4
1971	68	43	31	45	201	227	242	221	185	224	266	191	163	27	04/14	300	11/07	5.1
1972	119	80	63	42	257	263	235	175	134	155	128	83	145	30	04/23	289	05/23	4.6
1973	55	40	32	24	127	185	169	133	103	89	82	70	93	21	04/28	196	06/04	2.9
1974	53	41	25	24	183	181	124	65	42	33	26	19	68	15	04/18	216	05/17	2.2
1975	16	16	13	14	89	166	140	104	70	89	62	28	68	10	04/12	178	06/29	2.1
1976	40	63	65	68	84	146	238	181	163	281	333	352	168	23	06/01	374	12/30	5.3
1977	370	369	350	404	485	540	534	570	845	911	933	924	604	340	04/02	940	11/15	19.1
1978	877	861	856	691	642	853	913	887	863	966	953	930	858	600	04/29	980	10/13	27.1
1979	925	935	927	890	778	902	798	790	822	851	915	894	868	682	05/13	937	02/13	27.4
1980	854	886	900	918	859	825	864	878	941	938	939	974	897	769	05/30	979	09/24	28.4
1981	981	982	935	944	957	950	1060	1060	925	688	667	655	900	619	12/31	1120	07/25	28.4
1982	583	581	589	588	830	665	694	878	980	1010	1010	991	785	575	01/19	1030	09/29	24.7
1983	934	660	555	543	814	843	912	907	916	971	1000	987	839	533	04/19	1020	11/23	26.5
1984	955	939	937	1050	1120	1110	1060	967	789	835	956	989	976	778	09/15	1320	04/28	30.9

Table B6. Monthly and annual mean discharge (m^3/s), annual extremes and total discharge for the Nelson River at Kelsey generating station.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN	MIN. FLOW	DATE mmdd	MAX. FLOW	DATE mmdd	TOT_DIS m^3x10^9
1960	---	---	---	---	---	---	3280	3080	2900	2640	1920	1450	---	---	---	---	---	---
1961	1520	1440	1390	1370	1910	1940	2070	1990	1850	1630	1340	1020	1620	881	12/20	2560	08/02	51.2
1962	975	886	810	783	1660	2000	2110	2140	2150	2370	2170	1790	1660	742	04/14	2510	10/18	52.3
1963	1550	1440	1440	1450	2410	2570	2870	2680	2530	2430	2160	1630	2100	1310	04/14	3000	07/11	66.2
1964	1420	1380	1240	1240	2040	2350	2330	2400	2440	2330	2130	1710	1920	1150	04/06	2690	09/13	60.8
1965	1480	1450	1430	1420	2730	3300	3610	3540	3520	3310	2780	2670	2610	1270	04/11	3770	09/14	82.4
1966	2340	2230	2290	2400	3290	4400	4800	4530	4060	3670	2860	2430	3280	2160	02/03	4980	07/22	103.0
1967	2380	2290	2260	2300	2910	3920	3790	3450	3110	2770	2350	1940	2790	1610	12/31	4020	06/08	88.0
1968	1720	1700	1690	1740	2460	2720	2780	2670	2790	2770	2660	2510	2350	1570	03/05	3340	12/25	74.4
1969	2300	2170	2420	2660	3280	3320	3230	3380	3640	3670	3060	2890	3010	2040	01/14	3820	09/09	94.9
1970	2550	2520	2510	2600	3320	3810	4110	3900	3570	3110	2970	2340	3110	2260	12/16	4190	07/06	98.1
1971	2370	2280	2480	2640	3560	3820	3790	3360	3140	2900	2400	2200	2920	1950	11/22	3990	07/09	92.1
1972	2070	2040	2130	2360	3550	3930	3750	3260	2920	2620	2140	1730	2710	1600	12/13	4160	06/16	85.7
1973	1780	1770	1790	1990	2430	2170	1860	1800	1600	1700	1980	1940	1900	1440	09/13	2660	06/04	60.0
1974	1890	1920	2030	2140	2760	3410	3880	3870	3590	3440	3060	2370	2870	1830	02/05	3960	07/29	90.5
1975	2320	2270	2380	2340	2920	3210	3050	2860	2760	3110	3180	2410	2740	2200	02/06	3430	07/01	86.3
1976	2470	2170	2030	2170	2820	3000	2880	2040	1740	1940	2020	1840	2260	1600	09/18	3170	09/08	71.5
1977	1710	1640	1660	1550	857	1100	1150	999	1210	1270	1850	1900	1410	419	05/08	2120	11/18	44.3
1978	1790	1830	1960	1690	1430	1250	1170	1250	1440	2180	2500	2560	1750	971	07/10	2750	11/07	55.3
1979	2490	2540	2420	2080	2910	3900	4030	2890	1530	1830	2450	2290	2610	1380	09/06	4080	07/07	82.5
1980	2100	2070	2160	1980	1340	1180	979	1090	1320	1740	2140	2150	1680	684	07/21	2260	03/10	53.3
1981	2140	2170	1820	915	940	966	1320	952	1320	1770	2330	2170	1560	497	08/03	2470	11/29	49.3
1982	1840	1800	1690	1610	1890	1460	1500	1490	1860	2330	2440	2300	1850	1090	07/01	2690	11/10	58.4
1983	2190	2240	2300	2340	1930	1780	1650	1710	1750	1990	2320	2220	2030	1520	05/04	2480	11/18	64.1
1984	2180	2080	2180	1860	1560	1610	1570	1550	1690	1880	1990	2080	1850	1370	05/08	2270	01/01	58.6

Table B7. Monthly and annual mean discharge (m^3/s), annual extremes and total discharge for the Nelson River at Sea River Falls.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN	MIN. FLOW	DATE mmdd	MAX. FLOW	DATE mmdd	TOT_DIS m^3x10^9
1967	---	---	---	---	---	---	---	---	---	361	307	177	---	---	---	---	---	---
1968	174	175	165	220	330	380	385	383	406	383	394	260	305	159	03/25	487	11/13	9.6
1969	281	300	312	422	596	597	592	577	575	580	521	412	481	273	01/01	668	05/26	15.2
1970	398	398	393	481	675	720	761	682	554	483	457	357	531	328	10/03	807	07/22	16.8
1971	365	372	371	469	668	659	578	525	448	400	293	305	455	185	11/07	725	05/28	14.4
1972	319	316	320	496	673	648	563	487	402	348	297	202	423	183	12/30	728	05/15	13.4
1973	197	232	275	355	367	388	456	436	366	356	231	187	321	167	12/30	498	07/12	10.1
1974	---	177	294	474	699	879	883	814	708	---	---	---	---	---	---	---	---	---
1975	362	401	392	445	675	702	718	711	654	531	404	274	523	254	12/30	790	08/07	16.5
1976	246	241	250	362	420	426	424	451	358	218	92	87	298	85	12/31	513	08/18	9.4
1977	84	84	84	115	183	---	180	178	185	226	165	125	---	---	---	---	---	---
1978	118	121	129	171	449	503	551	546	541	495	387	236	355	117	01/15	623	09/23	11.2
1979	177	182	222	282	440	587	569	549	532	447	292	207	375	169	01/21	646	07/08	11.8
1980	213	214	216	324	472	477	508	488	478	400	304	208	359	182	12/31	570	08/29	11.3
1981	176	173	186	240	315	349	424	430	386	330	211	151	282	140	12/30	499	09/23	8.9
1982	133	126	123	171	385	483	552	583	463	375	289	212	326	122	03/16	735	08/09	10.3
1983	197	191	185	208	441	514	558	547	473	420	323	210	357	179	04/11	621	08/03	11.2
1984	204	199	193	280	393	447	482	462	342	313	181	147	304	143	12/28	545	06/30	9.6

Table B8. Monthly and annual mean discharge (m^3/s), annual extremes and total discharge for the Nelson River at Bladder Rapids.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEAN	MIN. FLOW	DATE mmdd	MAX. FLOW	DATE mmdd	TOT_DIS $m^3 x 10^9$
1958	---	---	---	---	---	---	---	---	---	2090	2030	1810	---	---	---	---	---	---
1959	1350	1280	1040	1110	2090	2750	2970	2940	2930	2710	2420	1870	2130	966	03/31	3060	09/09	67.1
1960	1750	1860	1980	2020	2650	3180	3040	2840	2690	2450	2130	1650	2350	1490	12/31	3260	06/15	74.4
1961	1390	1380	1360	1520	1920	2150	2080	1970	1810	1650	1380	852	1620	697	12/20	2220	06/07	51.1
1962	853	826	769	815	1760	2040	2230	2260	2370	2450	2200	1550	1680	728	04/15	2550	10/11	53.0
1963	986	940	1240	1580	2070	2470	2650	2510	2440	2320	2050	1680	1920	917	02/03	2720	06/30	60.5
1964	1420	1330	1210	1210	1930	2200	2280	2240	2210	2100	1970	1600	1810	1190	03/21	2360	08/05	57.2
1965	1350	1320	1350	1580	2490	3280	3400	3410	3260	3220	2590	2550	2490	1310	01/11	3510	06/28	78.5
1966	2260	2090	2140	2580	3300	4270	4540	4230	3890	3520	2720	2350	3160	2050	02/05	4620	07/21	99.9
1967	2330	2240	2210	2290	3090	3750	3640	3320	3060	2600	2300	2010	2740	1980	12/21	3820	06/06	86.4
1968	1960	1850	1760	1770	2240	2610	2690	2610	2740	2700	2540	1990	2290	1700	04/08	2860	09/21	72.4
1969	2090	2150	2340	2700	3310	3310	3270	3230	3350	3290	3130	2680	2910	1930	01/01	3540	09/05	91.7
1970	2530	2460	2740	2790	3250	3640	3820	3600	3240	2940	3000	2580	3050	2350	12/31	3910	07/11	96.2
1971	2200	2390	2450	2760	3440	3590	3410	3120	2920	2710	2280	2010	2780	1990	12/21	3650	05/29	87.6
1972	1940	2050	2360	2570	3380	3610	3410	3090	2790	2540	2210	1870	2650	1760	12/11	3820	06/14	83.9
1973	2010	2030	2100	2170	2400	2030	1920	1830	1630	1800	1970	1850	1980	1500	09/16	2530	05/25	62.4
1974	1830	1750	1820	2410	3330	4160	4480	4270	3860	3690	3330	2580	3130	1670	02/27	4560	07/14	98.8
1975	2180	2160	2510	2780	3380	2720	3190	3330	3050	3750	3650	3080	3070	2020	01/30	3940	08/26	96.9
1976	3310	2820	2450	2520	3150	3220	2810	2060	1750	2270	2230	2350	2580	1680	09/15	3620	01/01	81.6
1977	1560	1490	1440	1050	922	1060	1060	1020	1050	1300	2350	1940	1350	878	05/10	2530	11/20	42.6
1978	1740	1630	1590	1620	1680	1180	1180	1300	1590	2640	2970	2750	1820	1120	06/09	3140	11/05	57.5
1979	2360	2220	2200	2300	3490	4570	4420	2320	1550	2290	3020	2330	2760	1250	08/31	4750	06/20	87.1
1980	2130	2060	1970	1960	1160	1200	1000	1150	1250	2060	2440	2350	1730	864	07/12	2590	11/03	54.6
1981	2220	1990	1550	1110	1040	915	1210	1170	1420	2240	2740	2210	1650	791	06/17	2860	11/08	52.0
1982	1960	1790	1650	1610	1770	1410	1490	1740	2370	2830	2990	2730	2030	1380	06/03	3070	11/12	64.0
1983	2680	2590	2560	2520	2160	1750	1860	1900	1880	2260	2830	2510	2290	1580	07/06	2930	11/07	72.2
1984	2360	2120	1990	2020	1640	1600	1750	1780	1840	2090	2270	2290	1980	1490	06/11	2430	01/01	62.6